INTERNATIONAL RENEWABLE ENERGY AGENCY

IRENA

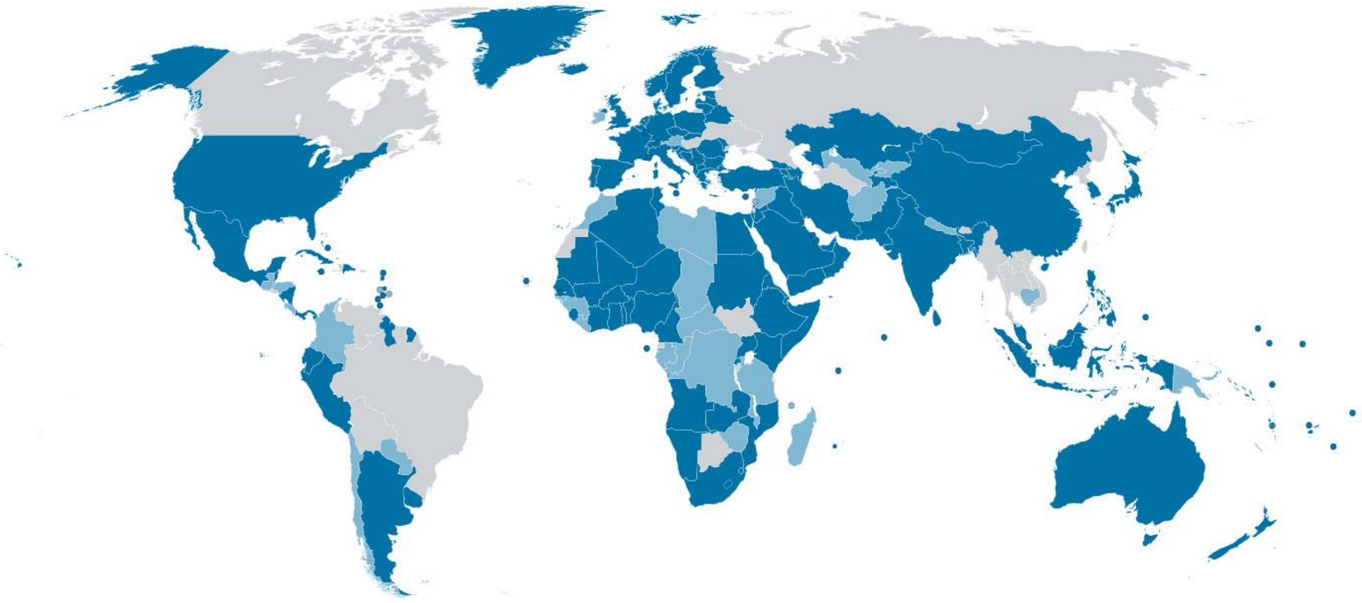
International Renewable Energy Agency

The Transformation of Power Systems with the Integration of Renewable Energies

Francisco Gafaro
Ruud Kempener
Bonn, 21 May 2015

The International Renewable Energy Agency

The Voice, Advisory Resource and Knowledge Hub for 170 Governments



Renewable energy can:

- Meet our goals for ***secure***, ***reliable*** and ***sustainable*** energy
- Provide ***electricity access*** to 1.3 billion people
- Promote ***economic development***
- At an ***affordable cost***

Outline

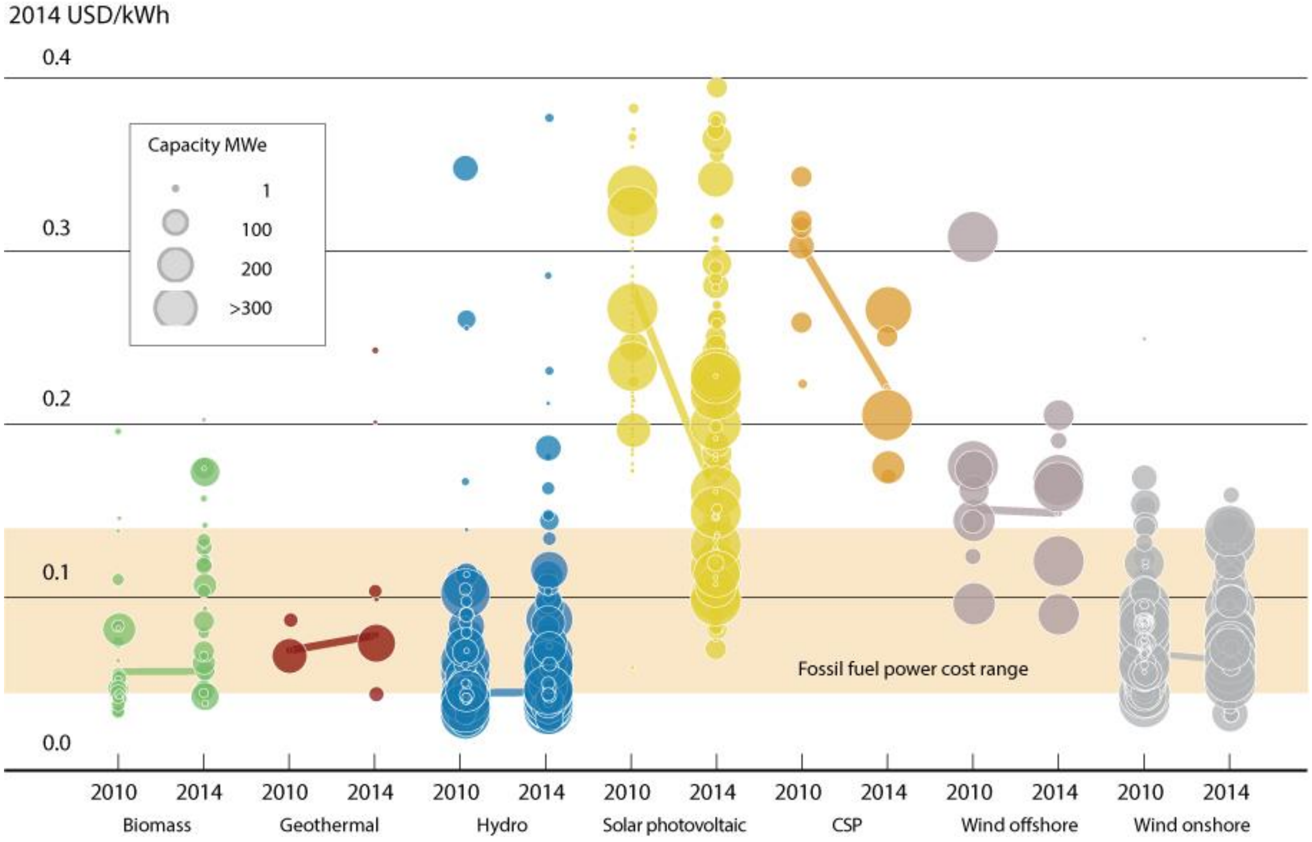
The deployment of renewable energy resources

The changes in the operation of the power systems

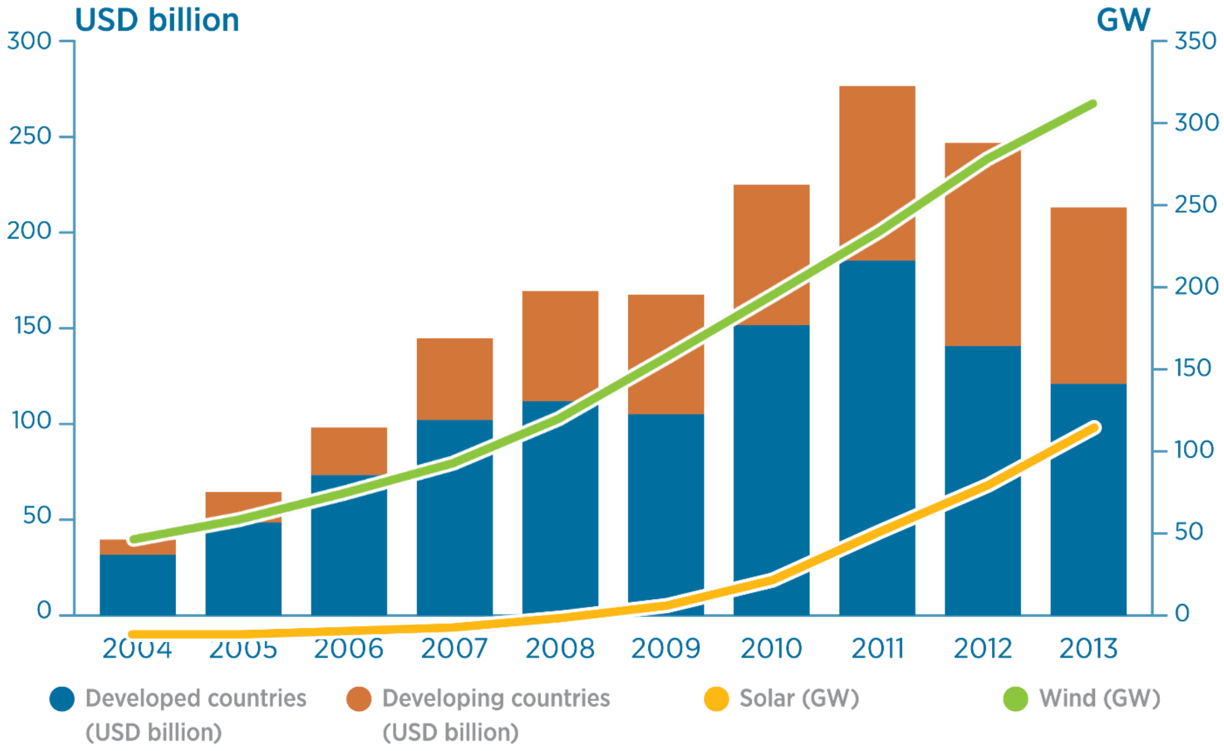
From integration to transformation of the power sector

THE DEPLOYMENT OF RENEWABLE ENERGY RESOURCES IN POWER SYSTEMS

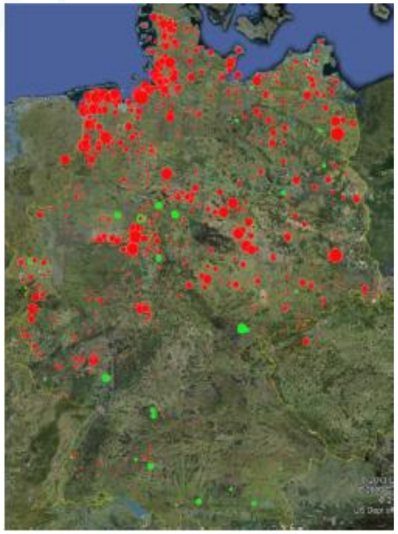
Renewables competitiveness continues to improve …

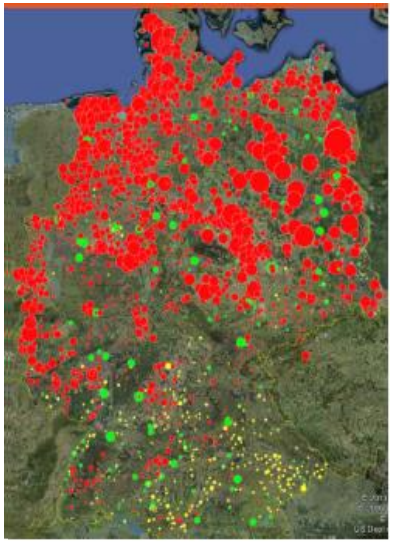


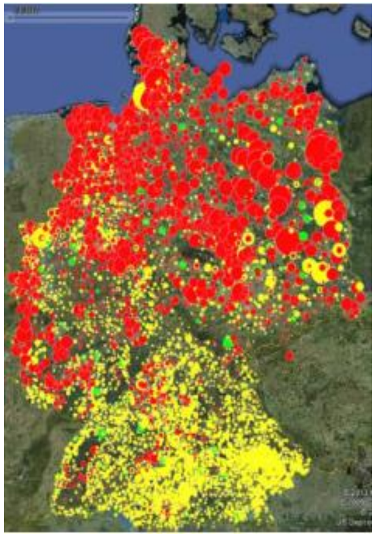
… and their share in the total electricity production is increasing



Power systems don’t look the same anymore







around 30.000 plants

around 220.000 plants

around 1.500.000 plants

2000

2006

2014

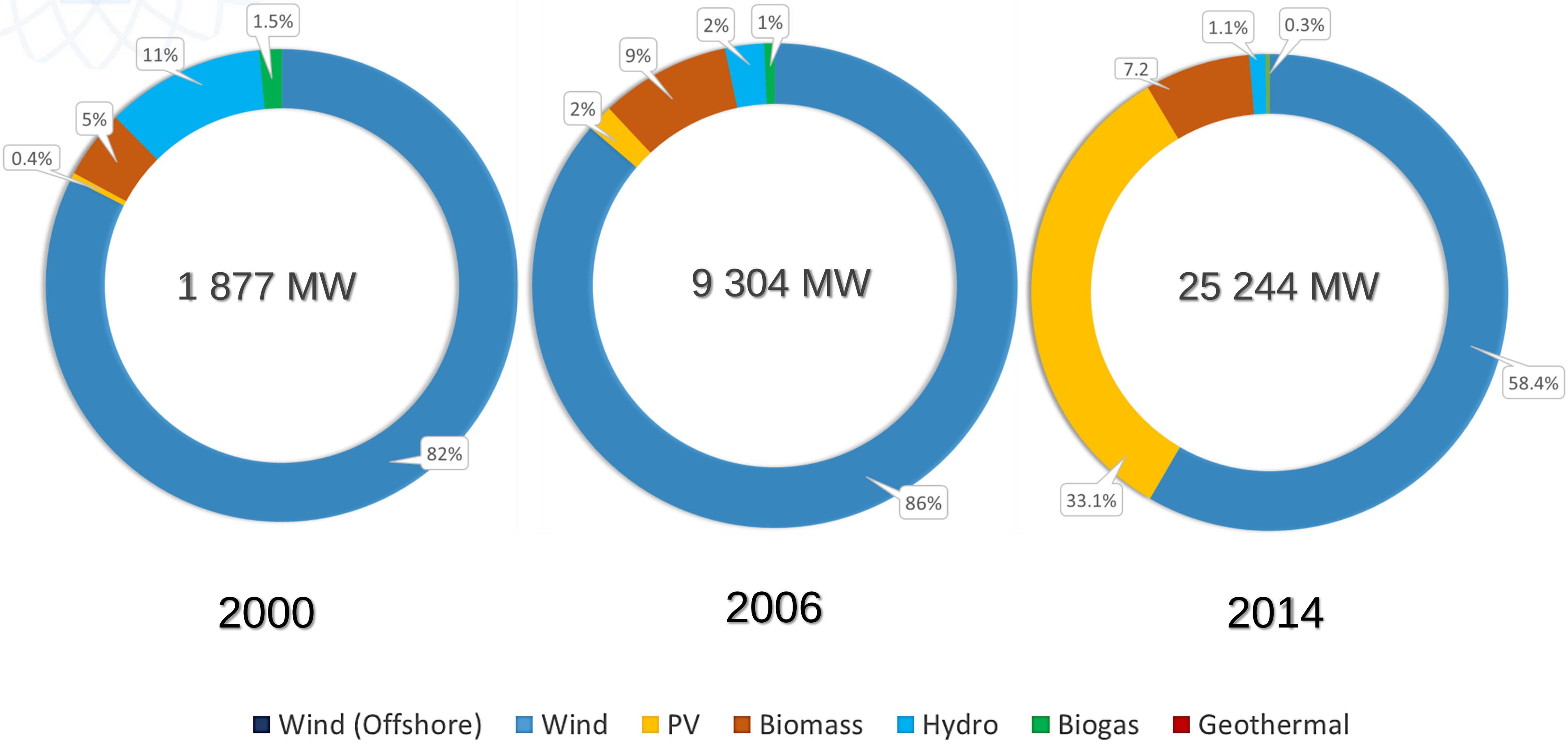
🔴 Wind

🟡 Photovoltaics

🟢 Biomass

Source: 50Hertz

Installed capacity Germany 50Hertz area

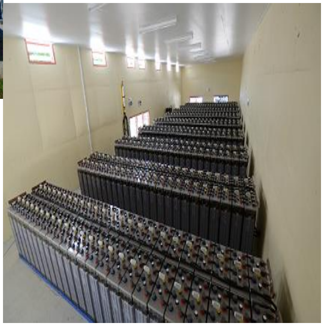


Source: 50Hertz

The transformation is not only happening in large systems

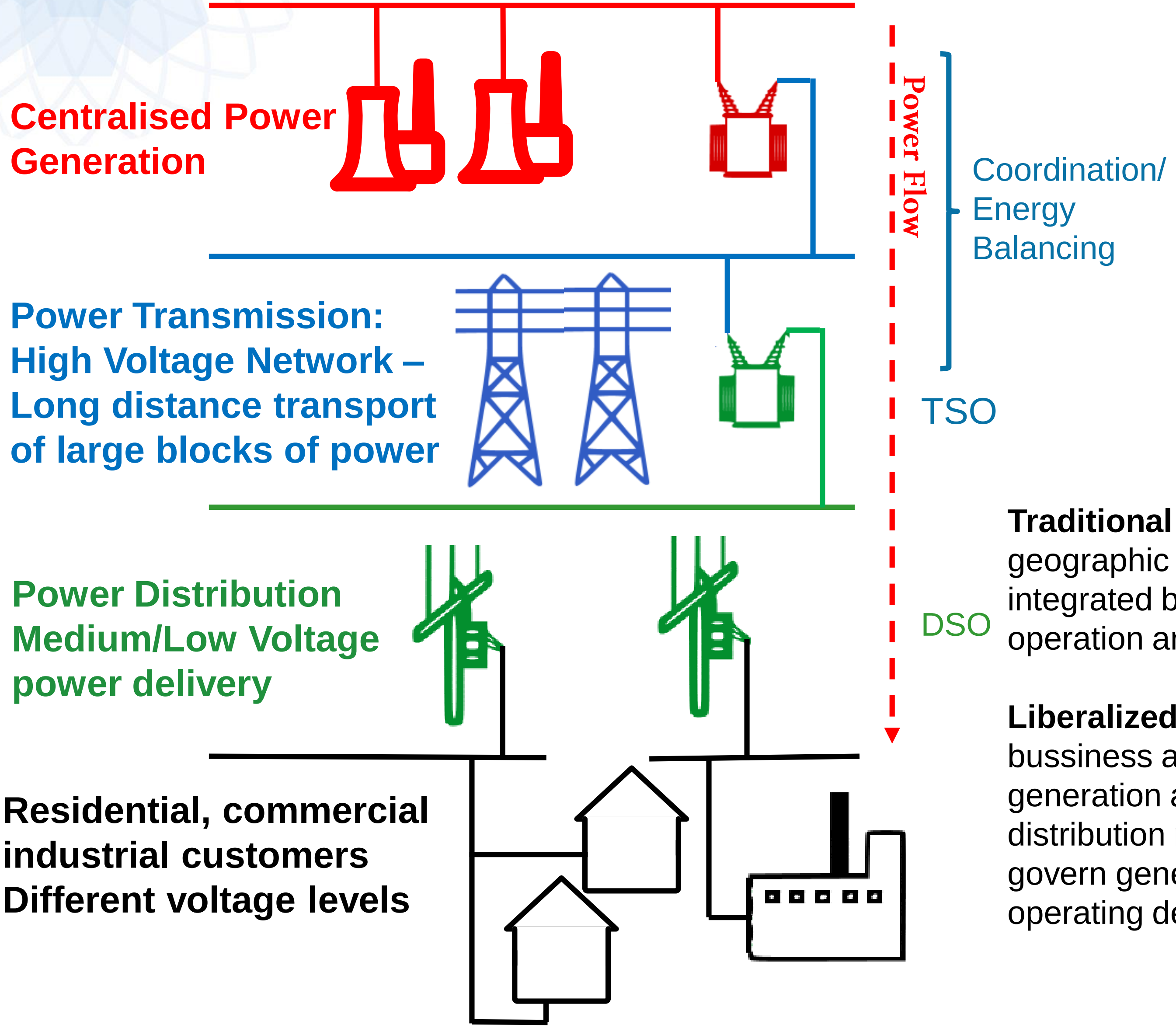
- Most islands around the world today are dependent on imported fossil fuels for the majority of their energy needs
- For reasons of scale and isolation, energy infrastructure costs are higher, and the severe impact of oil price and supply volatility is exacerbated by the small size of local markets.
- The deployment of RET can have a transformational impact on SIDS energy security, employment generation, and economic and social well-being
- Many SIDS already started the transformation of their power systems
- IRENA is supporting the efforts of islands in incorporating higher shares of renewable energies with concrete and practical actions **like the analyses of the islands' grid stability**

Why Renewables in islands?
Hedge against price and supply volatility of fossil fuels
Cost effective
Sustainable



THE CHANGES IN THE OPERATION OF POWER SYSTEMS

The traditional power supply chain



Centralised Power Generation

Power Transmission: High Voltage Network – Long distance transport of large blocks of power

Power Distribution Medium/Low Voltage power delivery

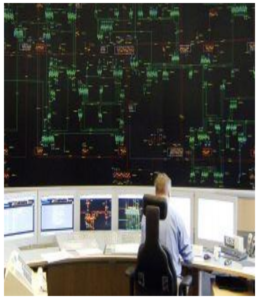
Residential, commercial industrial customers Different voltage levels

Power Flow

Coordination/ Energy Balancing

TSO

DSO



Source: Amprion GmbH

Economic Flow

Traditional Context: Monopolies with geographic franchises/vertically integrated bussinesses/centralized operation and expansion

Liberalized Context: Unbundle bussiness activities/ competitive generation and retailing/transmission and distribution natural monopolies/market govern generation investment and operating desisions

Power system operation

Power system operation aims to **meet electricity demand at any time efficiently and reliably**

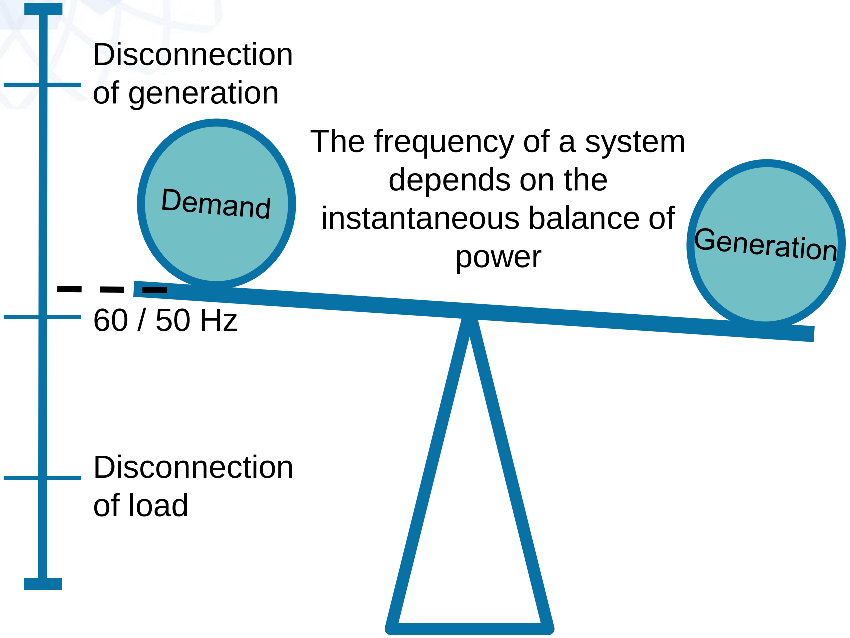
Major threats to power system operation
Lack of generation output to meet demand
Overloading of network components
Lack of operating reserves in both quantity and speed of reaction
Violation of voltage limits
Loss of system stability

System Adequacy → Sufficient generation and transport / distribution capacity

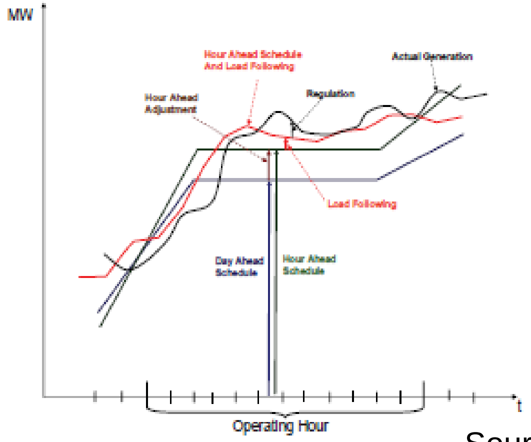
System Security → Robustness to changing conditions / fast and slow changes / small or large disturbances

Adapted from: Perez Arriaga MIT OpenCourseWare

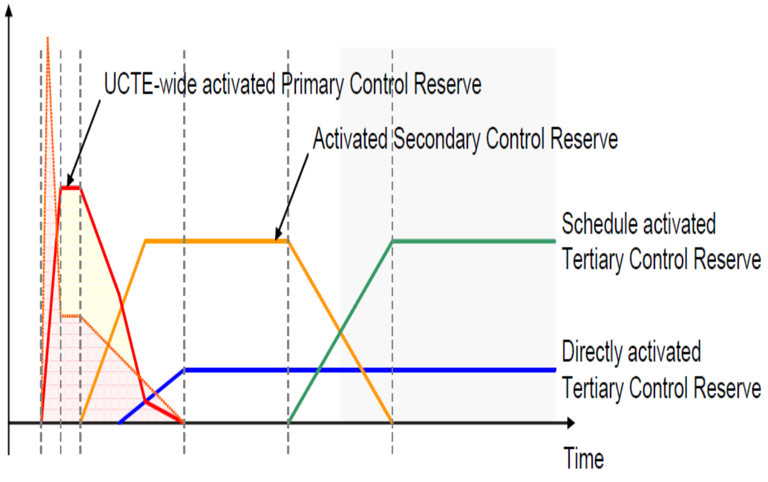
System security: Frequency Control



The frequency of a system depends on the instantaneous balance of power



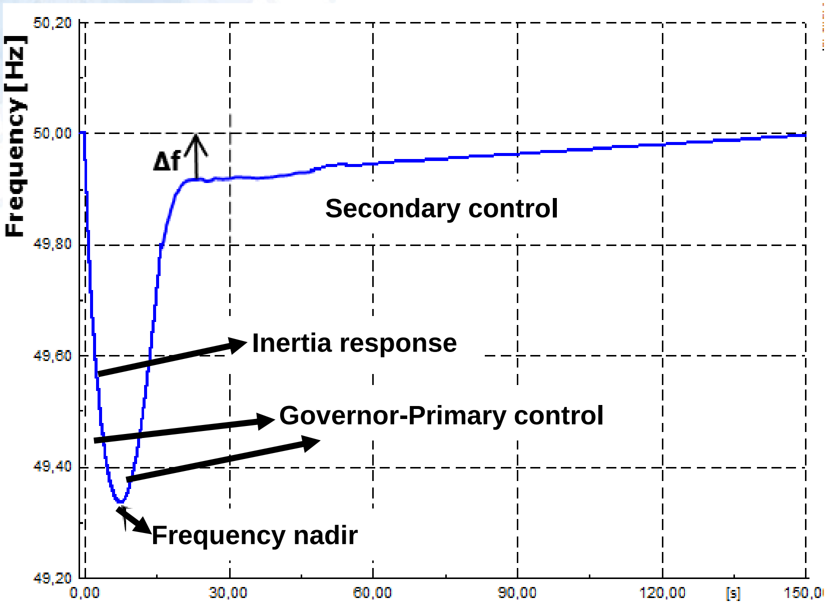
Source: CAISO

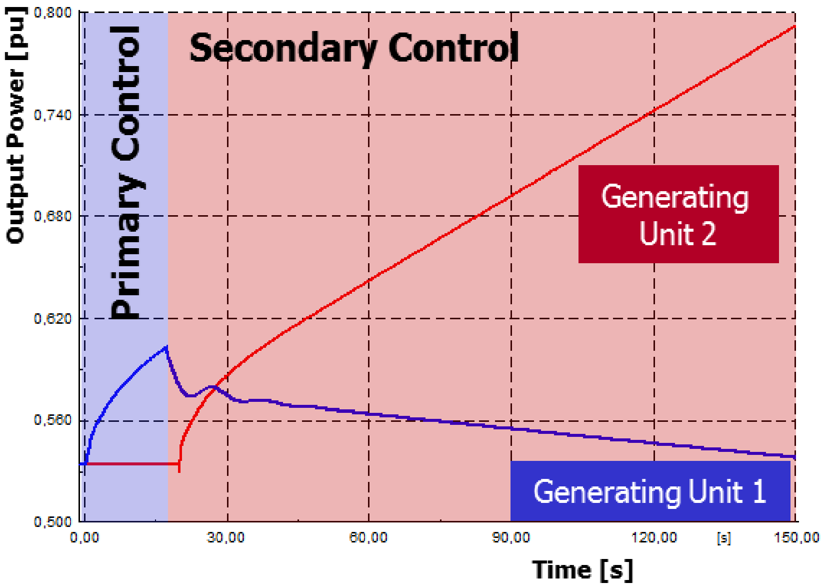


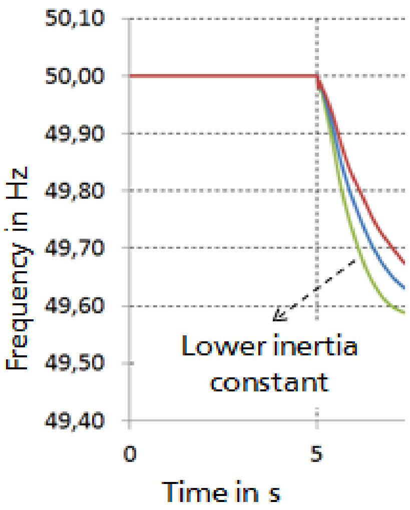
Source: ENTSOE

System operators schedule generation resources to meet demand, however 100% accuracy is not possible, **flexibility** to rapidly adapt schedules to changing conditions and **regulating reserves** to cover unavoidable deviations are necessary

System security: Frequency response







Higher inertia means slower decay rate of frequency, hence smaller frequency nadir

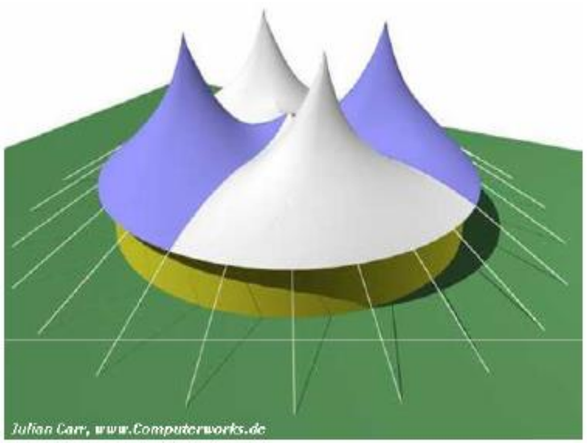
The frequency nadir corresponds to the maximum frequency deviation following the imbalance in the system

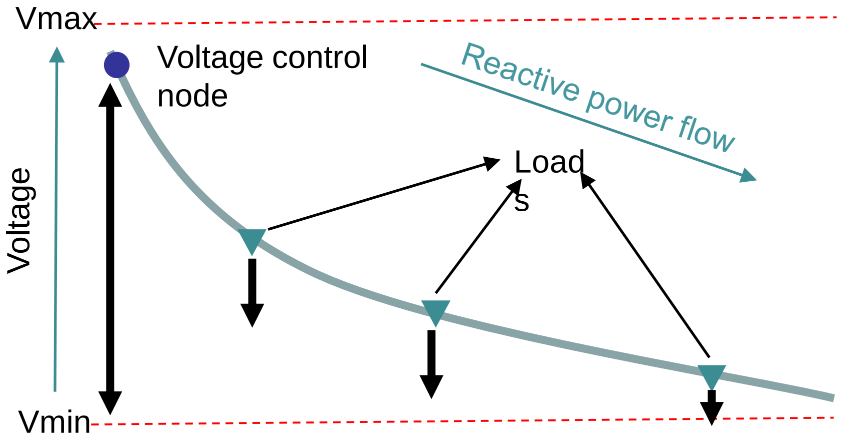
Nadir determines if load is disconnected in order to guarantee overall system stability

Nadir dependents on the inertia of the system and the amount of governors participating in primary control

Sufficient amount of primary reserve must be allocated to restore the balance in the system.

System security: Voltage control

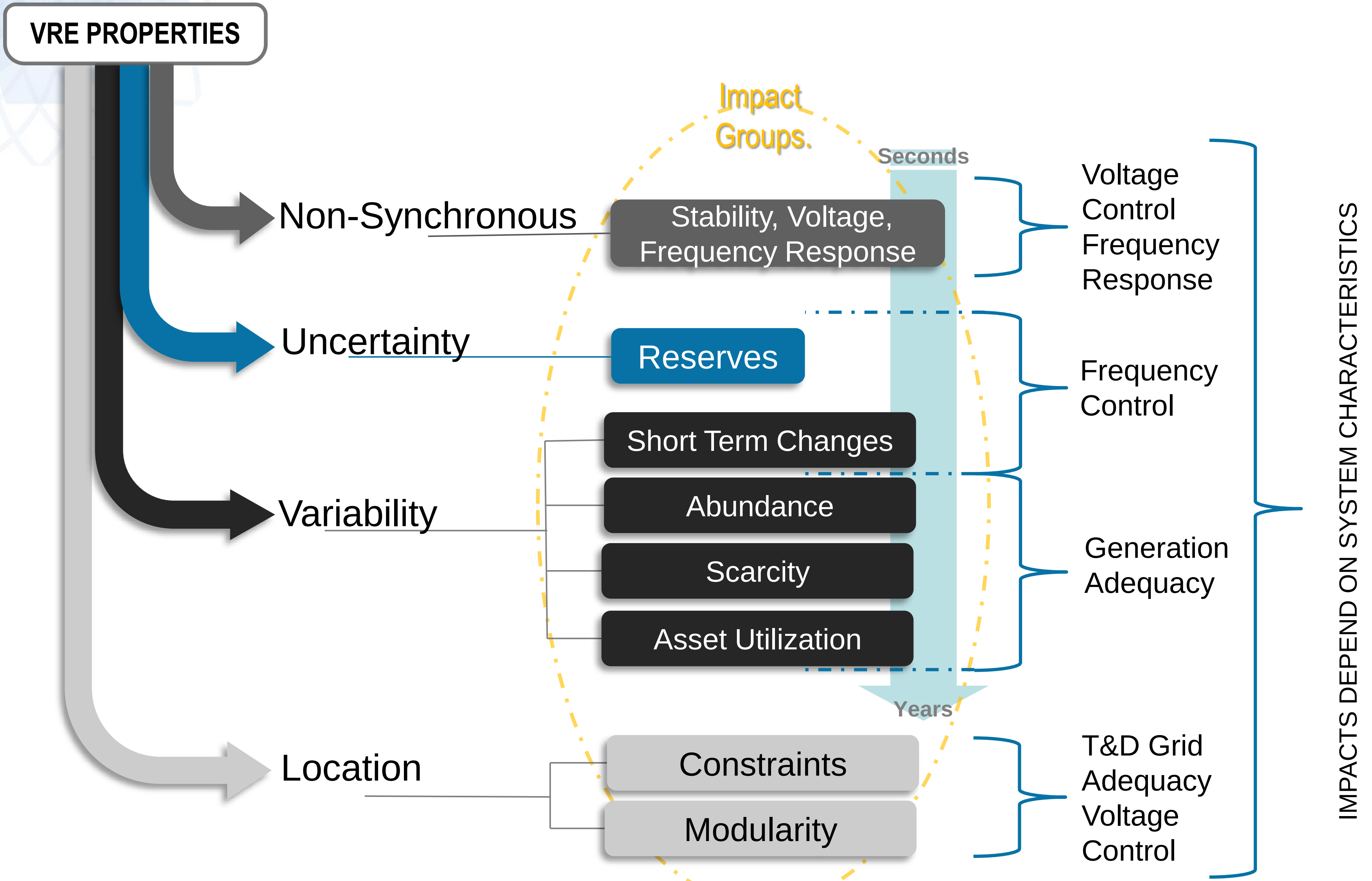




- Voltage at terminals of connection of equipment must be within acceptable limits (i.e. +/- 10% of nominal voltage)
- Voltage control is achieved by production and absorption of reactive power
- Reactive power sources:
  - Generators, capacitor banks, underground cables
- Reactive power sinks:
  - Generators, reactors, motors, transformers
- Methods of Voltage control:
  - Generator AVR
  - Controllable sources or sinks of reactive power (i.e. capacitor banks, SVC, STATCOM, etc)
  - Regulating transformers (i.e. tap changing transformers)

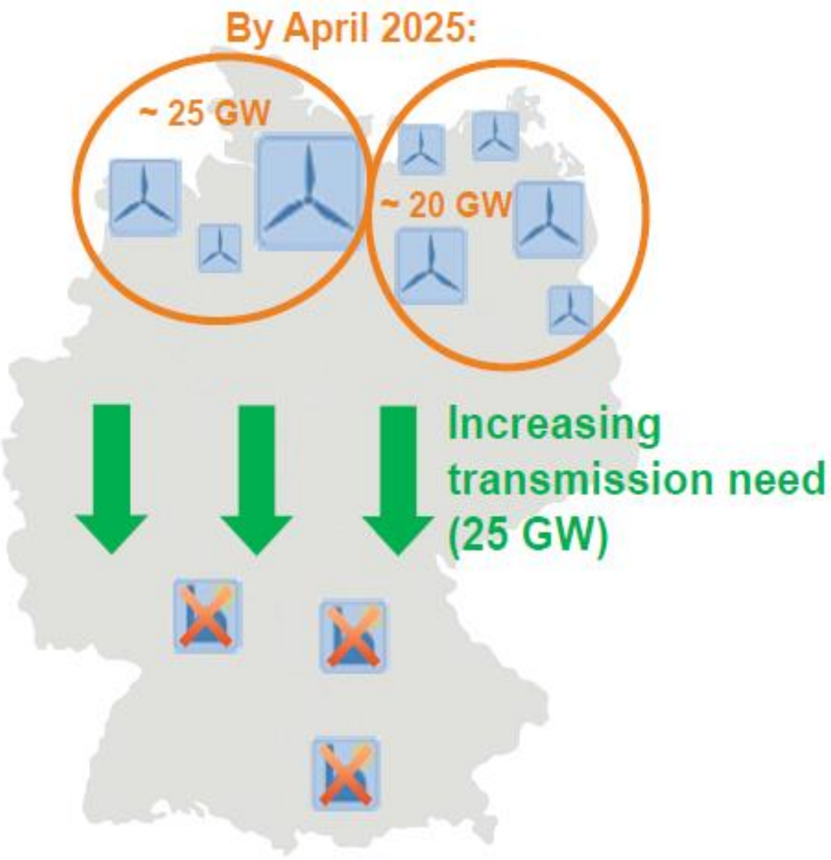
Injection of active power also affects voltage → higher influence in distribution networks (i.e. PV in distribution feeders affect voltage)

Properties of VRE and challenges



Source: Adapted from IEA, S. Muller

VRE properties and challenges example Germany

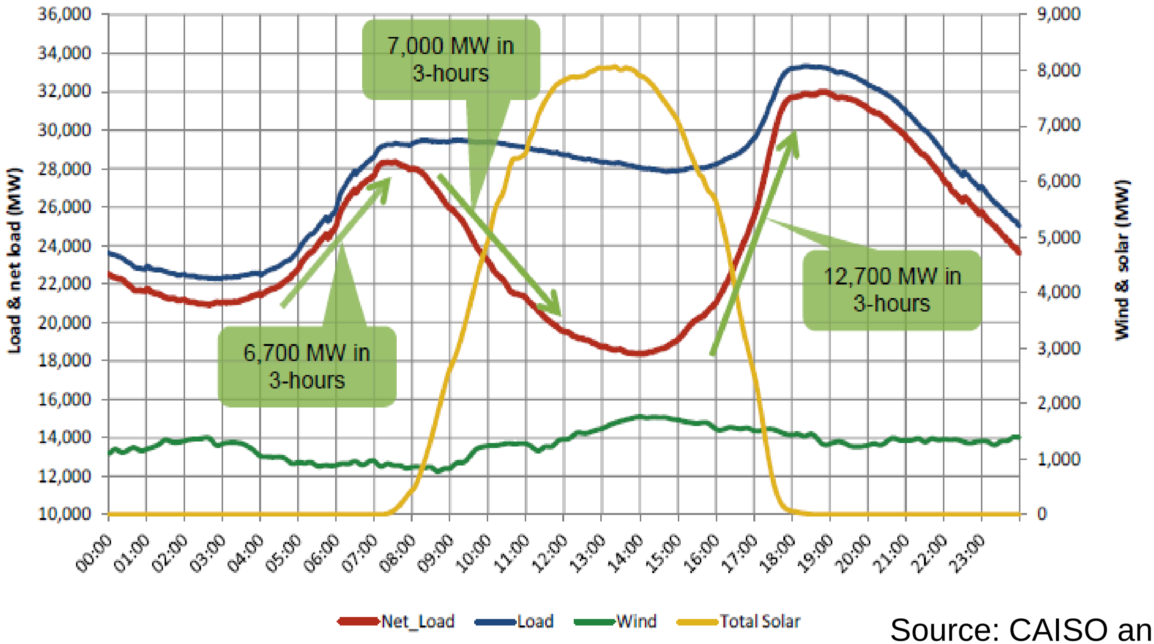


VRE Location:

- By 2025 expected wind power in north Germany would be around 45 GW
- Existing lines connecting north with south already high loaded
- Expected nuclear phase out of 8 GW

Source: 50 Hertz

VRE properties and challenges example California

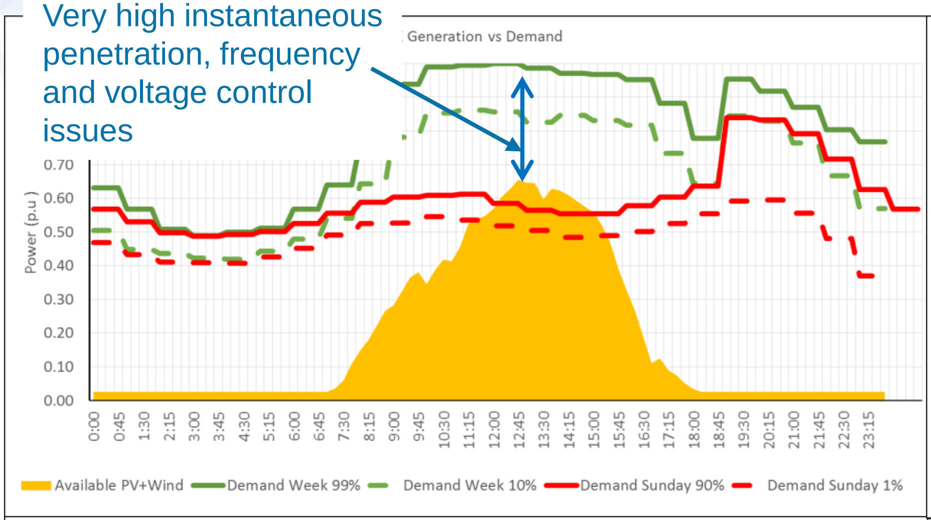


Source: CAISO and L. Jones

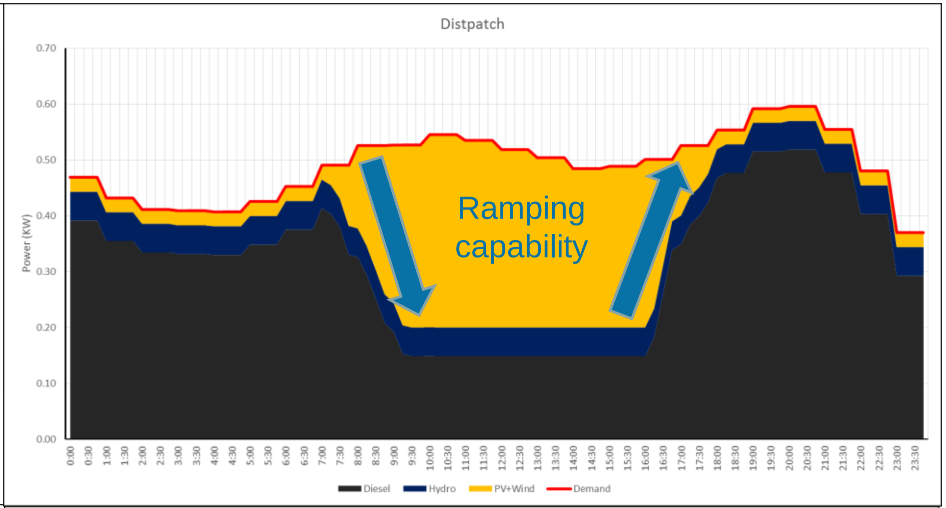
Flexibility Requirement

- Ramping capability (speed and quantity) to balance VRE production change
- Net load made up of ramps with significant capacity and shorter duration
- PV peak does not coincide with system peak load

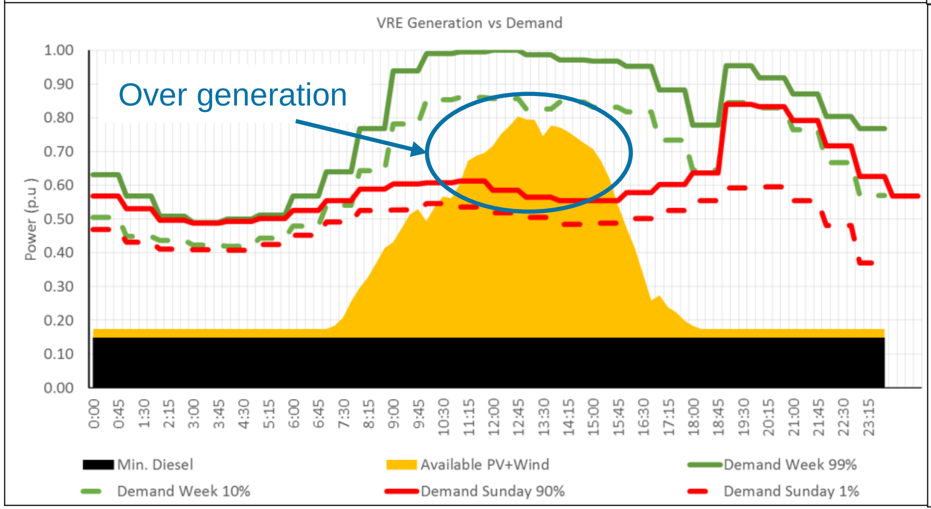
VRE properties and challenges example Pacific Island



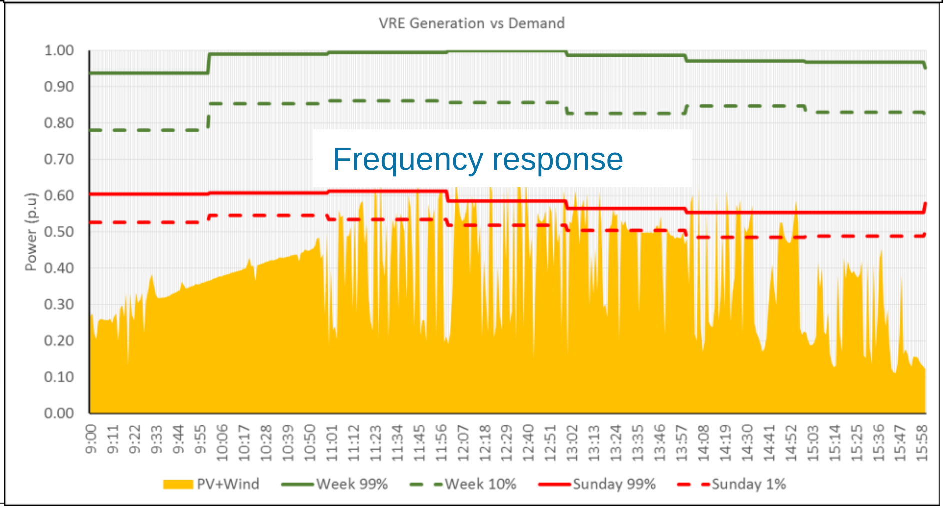
Very high instantaneous penetration, frequency and voltage control issues



Ramping capability

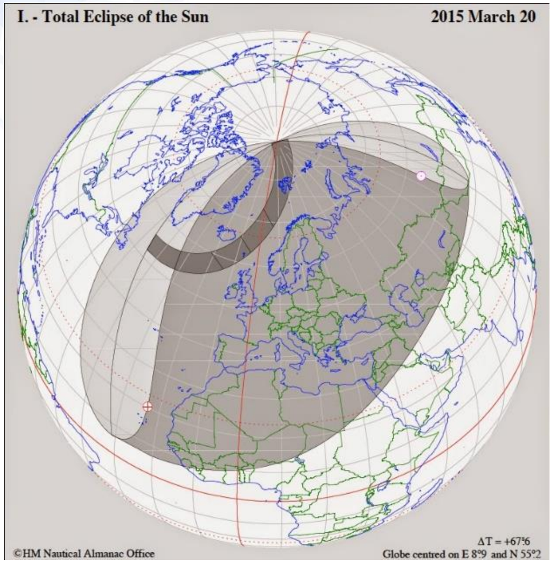


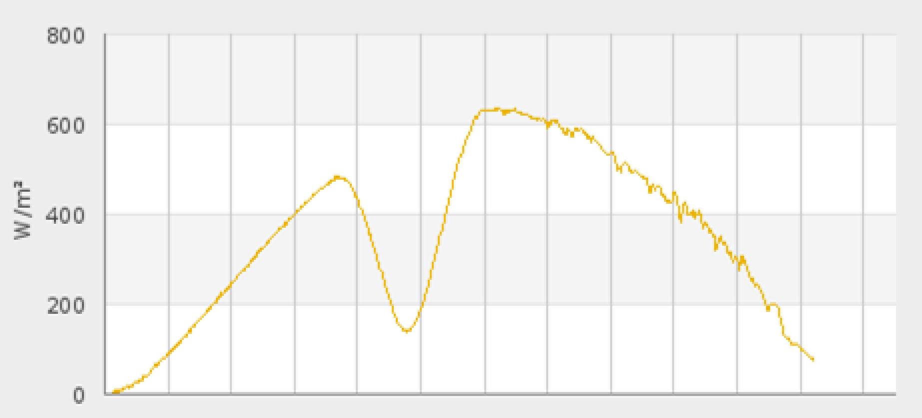
Over generation

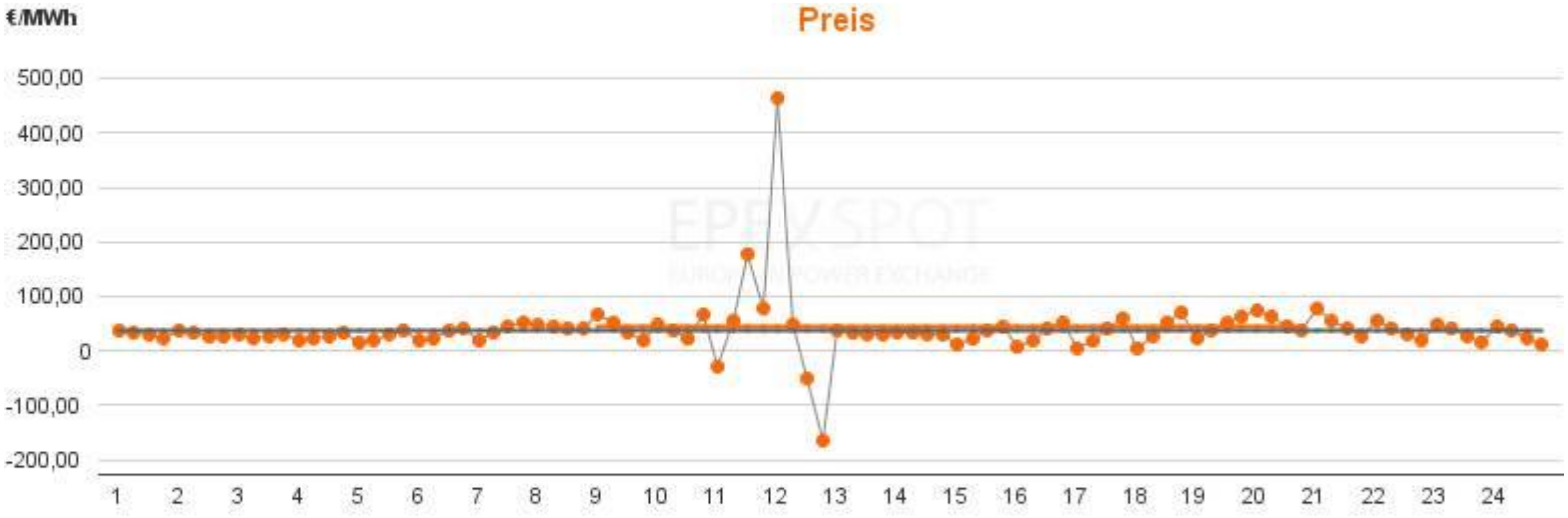


Frequency response

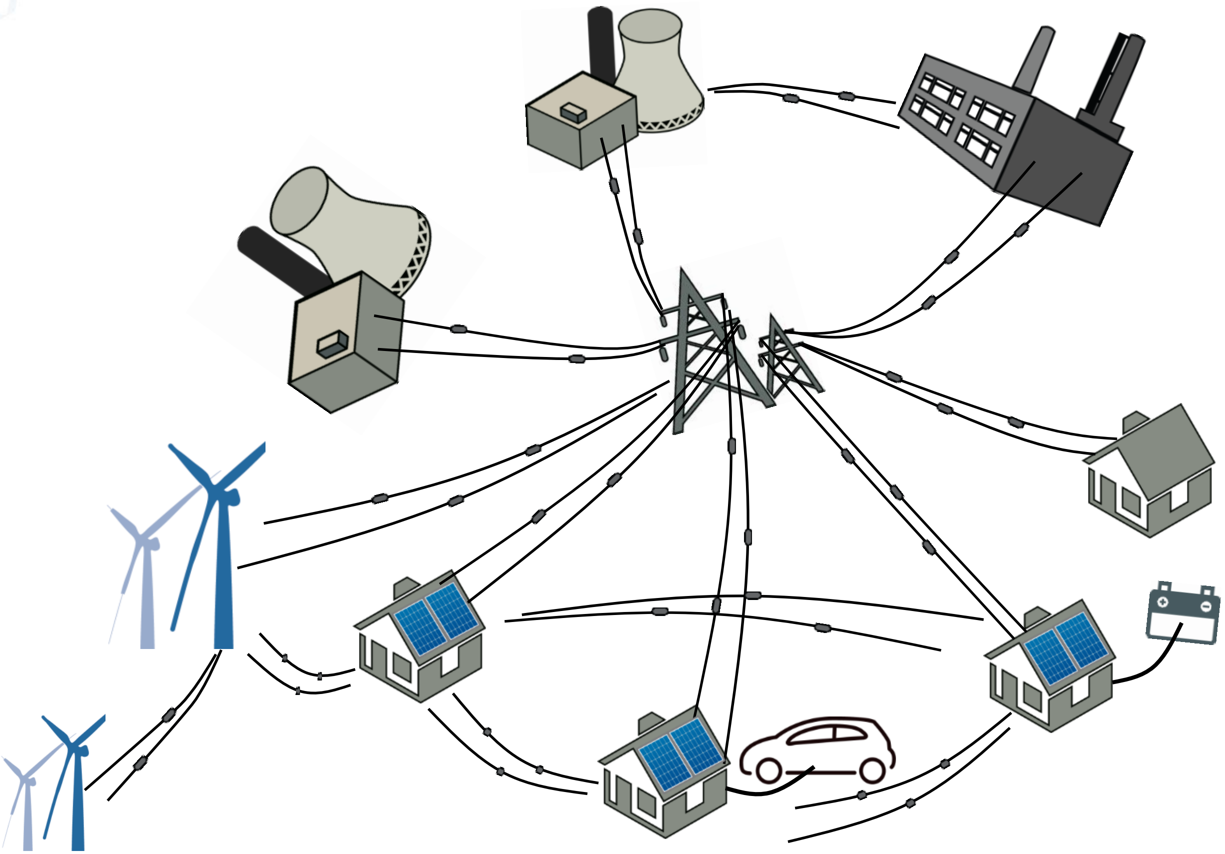
VRE properties and challenges example
Sun Eclipse March 2015







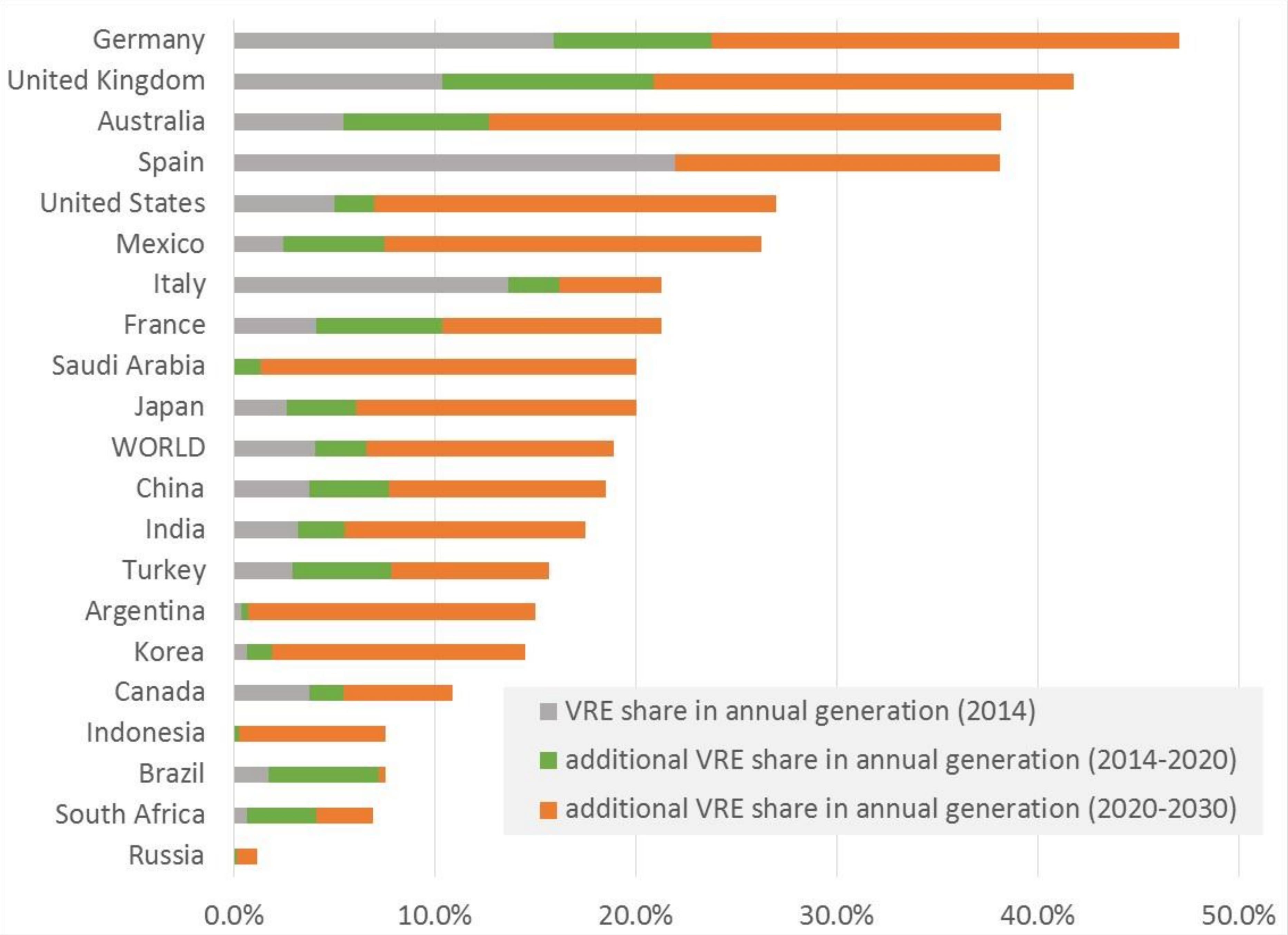
The Power System in under transformation



FROM INTEGRATION TO TRANSFORMATION

WHAT ARE THE SOLUTIONS?


BBC


Germany
United Kingdom
Australia
Spain
United States
Mexico
Italy
France
Saudi Arabia
Japan
WORLD
China
India
Turkey
Argentina
Korea
Canada
Indonesia
Brazil
South Africa
Russia
0.0%
10.0%
20.0%
30.0%
40.0%
50.0%
VRE share in annual generation (2014)
additional VRE share in annual generation (2014-2020)
additional VRE share in annual generation (2020-2030)

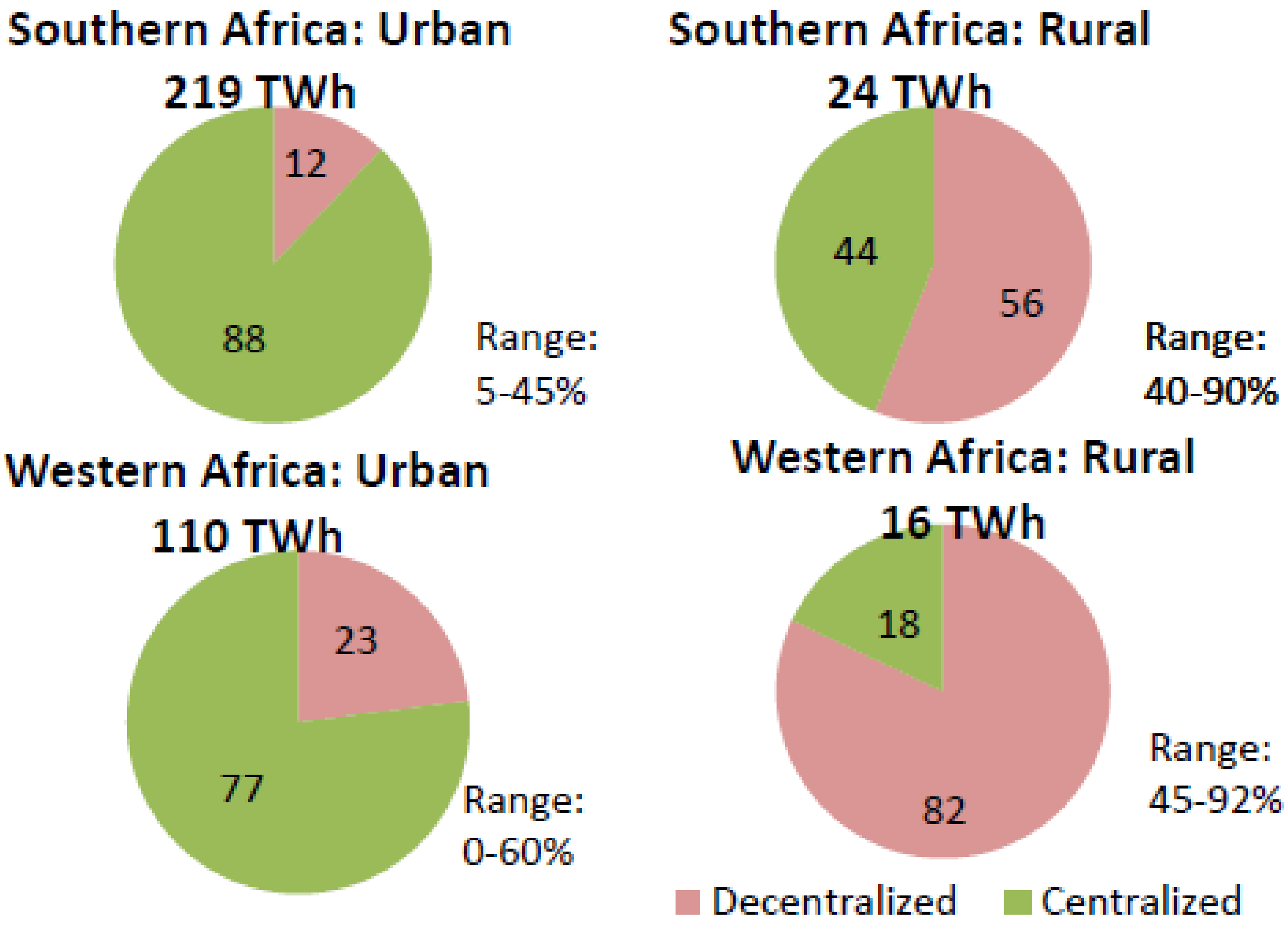
The context

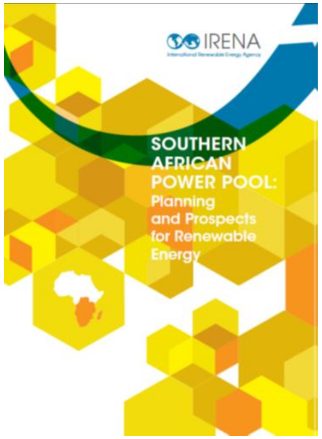
ISLANDS AND ISOLATED GRIDS
versus
INTERCONNECTED GRIDS

INTEGRATION
versus
TRANSFORMATION

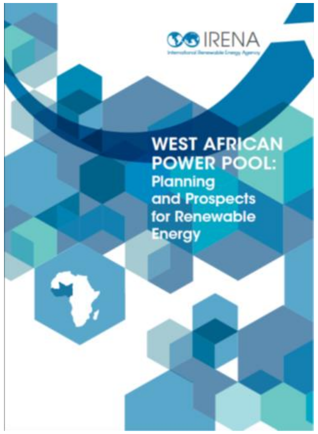
BROWNFIELD
versus
GREENFIELD

Islands and isolated grids



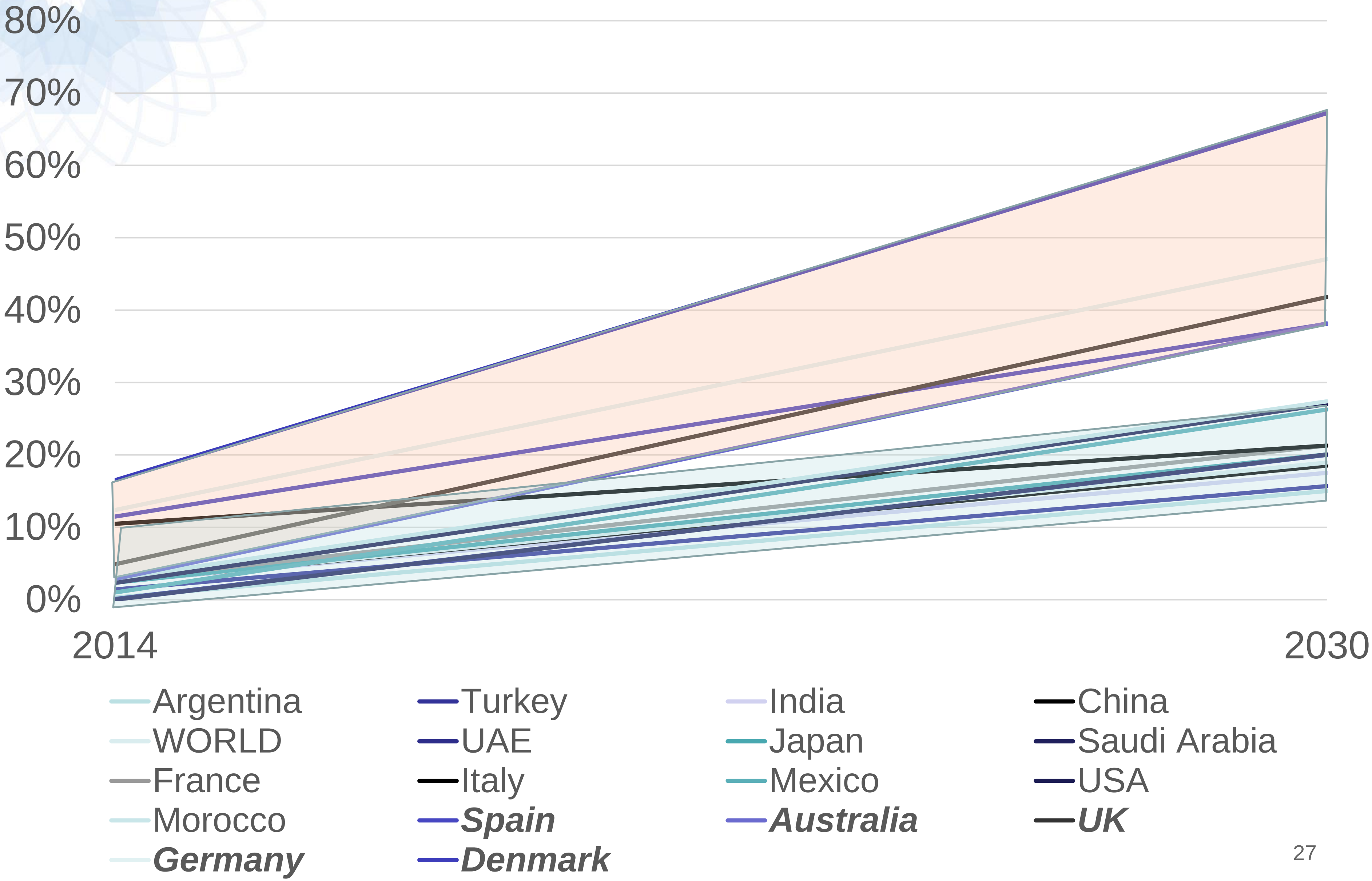

IRENA

SOUTHERN AFRICAN POWER POOL: Planning and Prospects for Renewable Energy

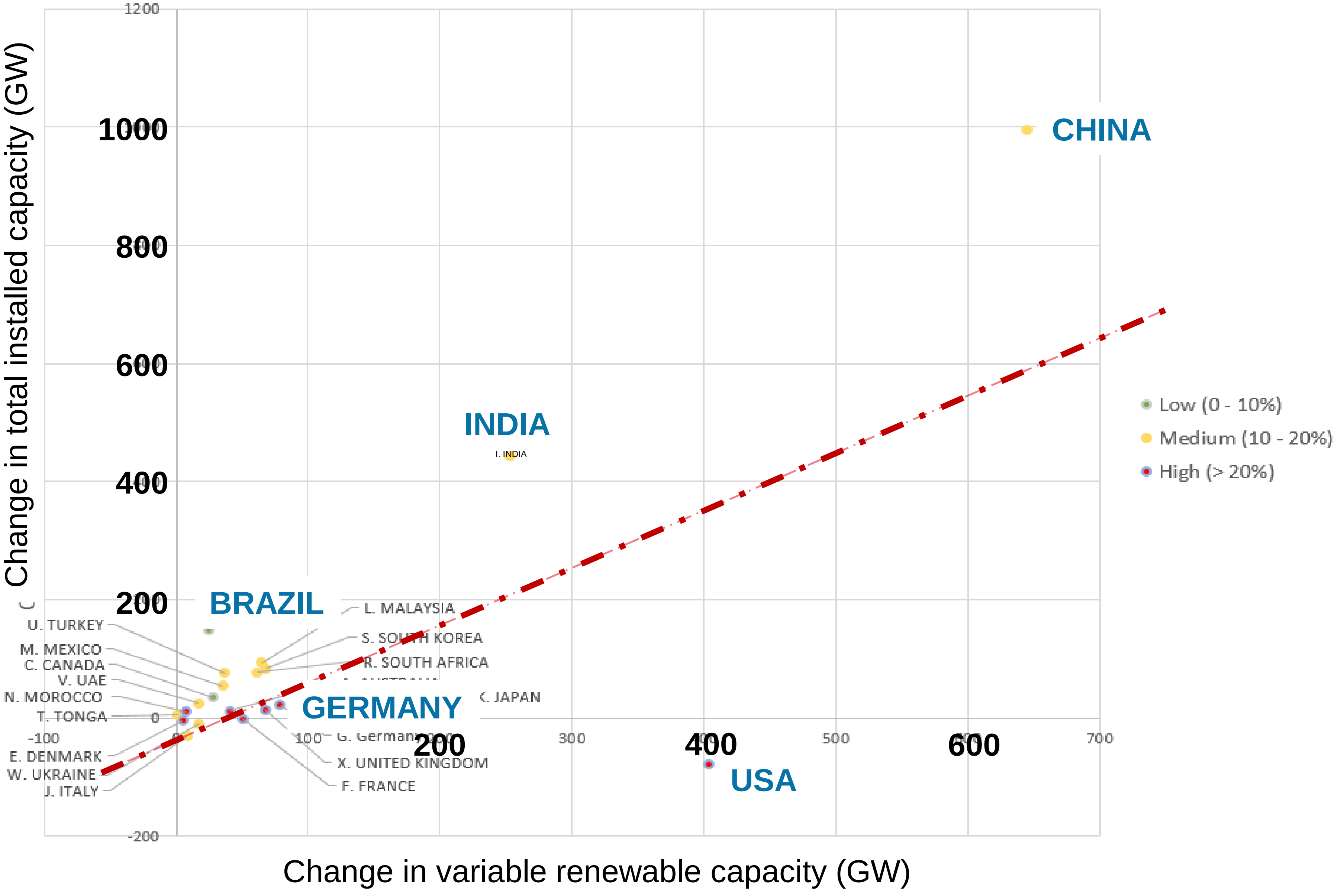

IRENA

WEST AFRICAN POWER POOL: Planning and Prospects for Renewable Energy

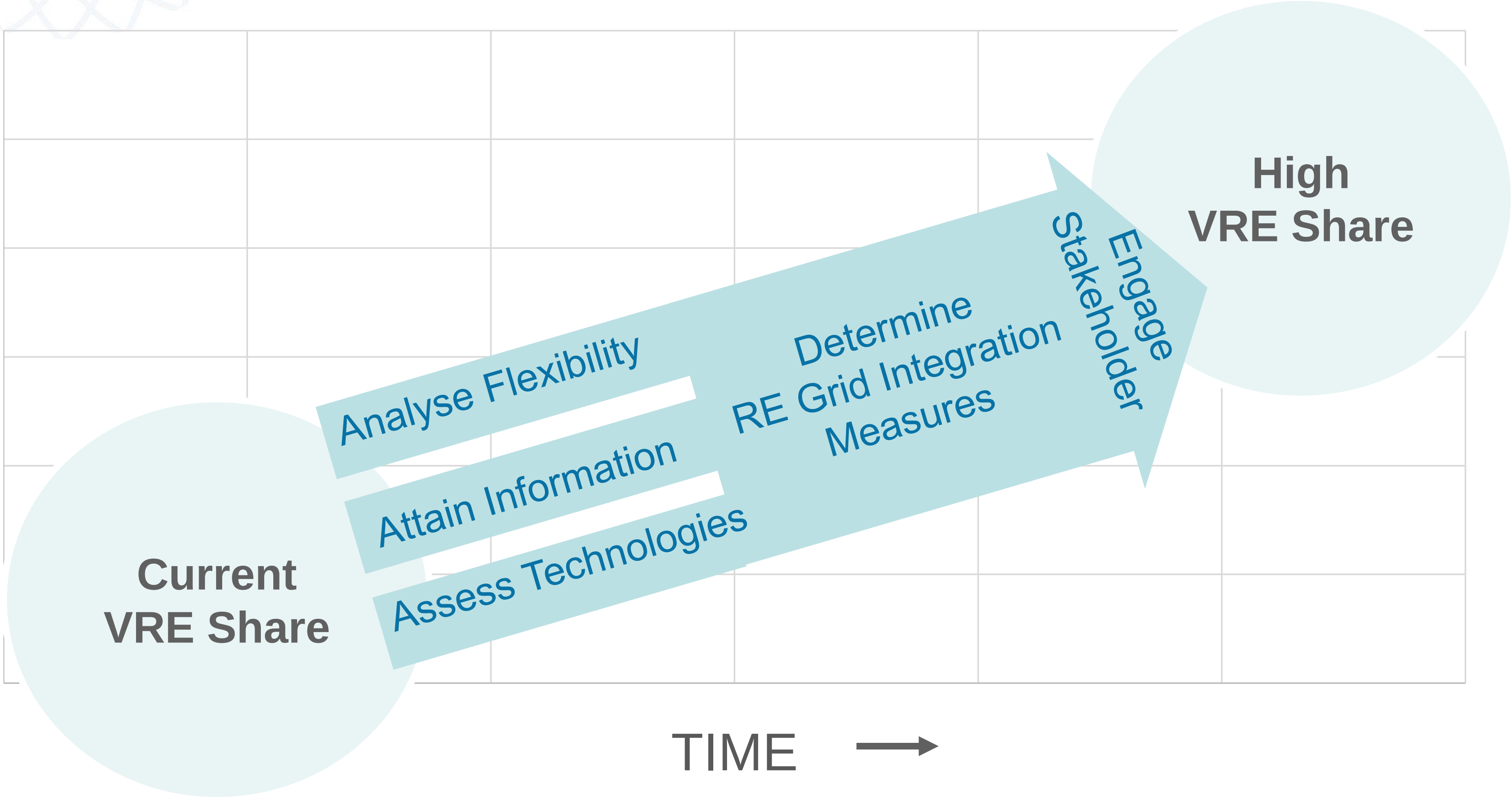
Integration versus transformation



Brownfield versus Greenfield



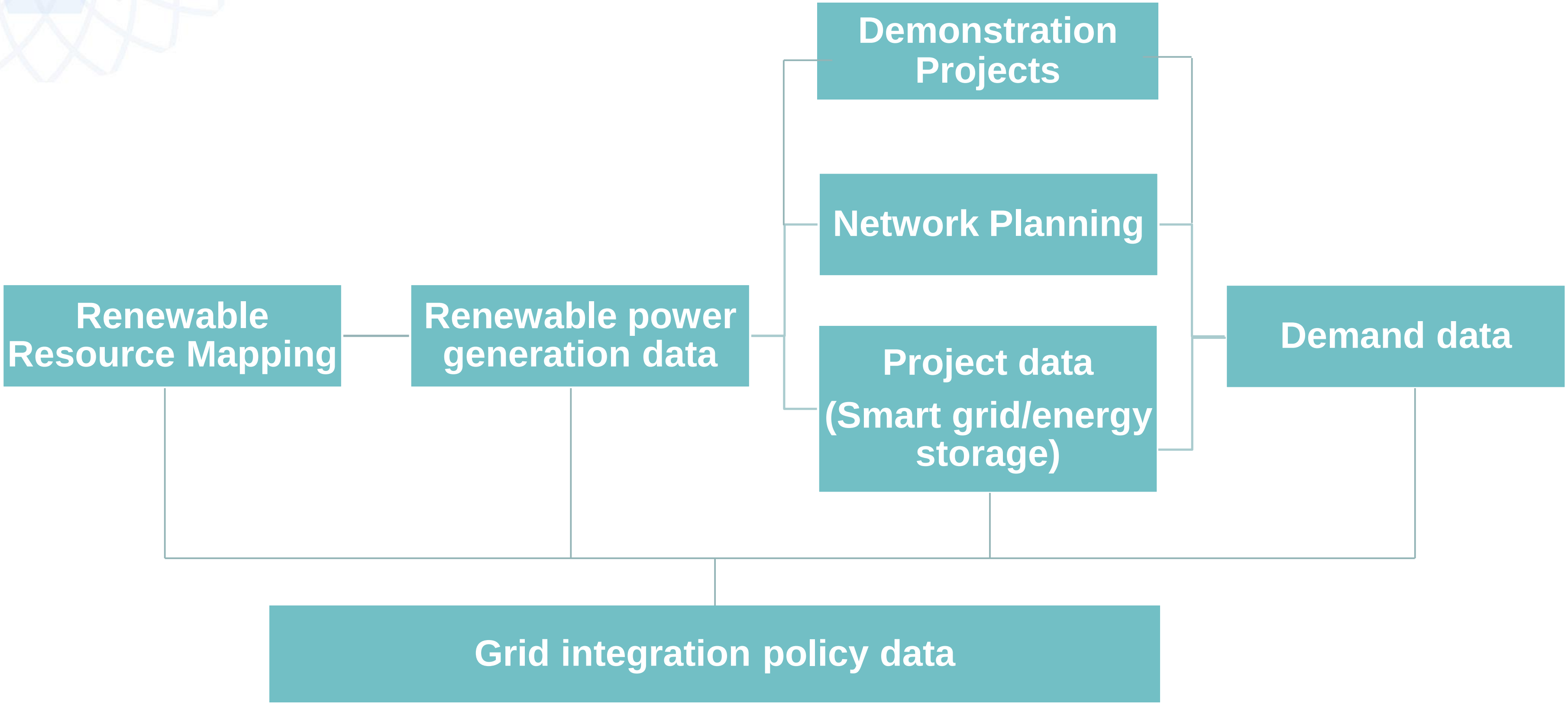
The three knowledge pillars for RE grid integration



Analyse flexibility

IRENA	IEA GIVAR	IEA-RETD RE-INTEGRATE
Grid infrastructure	Power area size (peak demand)	
	Internal grid strength	
	Interconnection (capacity and potential)	Interconnection
Institutional framework	No. of power markets	
	Investment opportunity	
Power generation mix	Geographical spread of VRE integration	Geographical distribution of VRE
		VRE portfolio
	Flexibility of dispatchable generation portfolio	Generation and storage flexibility

Attain information



Demonstration Projects

Network Planning

Renewable Resource Mapping

Renewable power generation data

Project data

(Smart grid/energy storage)

Demand data

Grid integration policy data

Asses technologies

Generation

- Smart inverters
- Advanced forecasting
- Flexibility upgrades
- Reserve capacity
- Virtual power plants
- Controllable VRE

Network

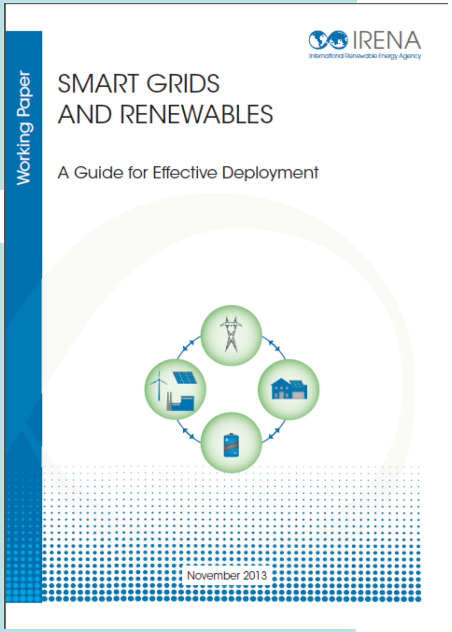
- Grid expansion
- HV AC/DC lines
- Distribution automation
- FACTS
- Dynamic line rating
- Synchrophasors
- Interconnectors

Demand

- Demand response
- Direct load control
- Advanced metering
- Advanced electricity pricing

Storage

- Distributed heat, cold storage
- Distributed battery and EV management
- CHP storage
- Pumped hydro



Working Paper

SMART GRIDS
AND RENEWABLES

A Guide for Effective Deployment

November 2013

Measures by stakeholder

Generators

- Simplifying administrative procedures

- Forecast incentive

- Performance reporting

-Ancillary service compensation (fast response, frequency regulation, reactive power control, reserve capacity etc.)

Network operators

- Congestion management

- Financial incentives for utilities

- Benefit demonstration

- Data ownership rights

- Integrated planning

Customers

- Participation in project planning

- Public awareness programs

- Acceptance for demand-side measures

- Connection charges for DG

Power suppliers and trading companies

- Competitive wholesale and retail electricity market

- Evaluation and establishment of new business models

- New tariff schemes

Equipment manufacturers

- Technology standards and grid codes

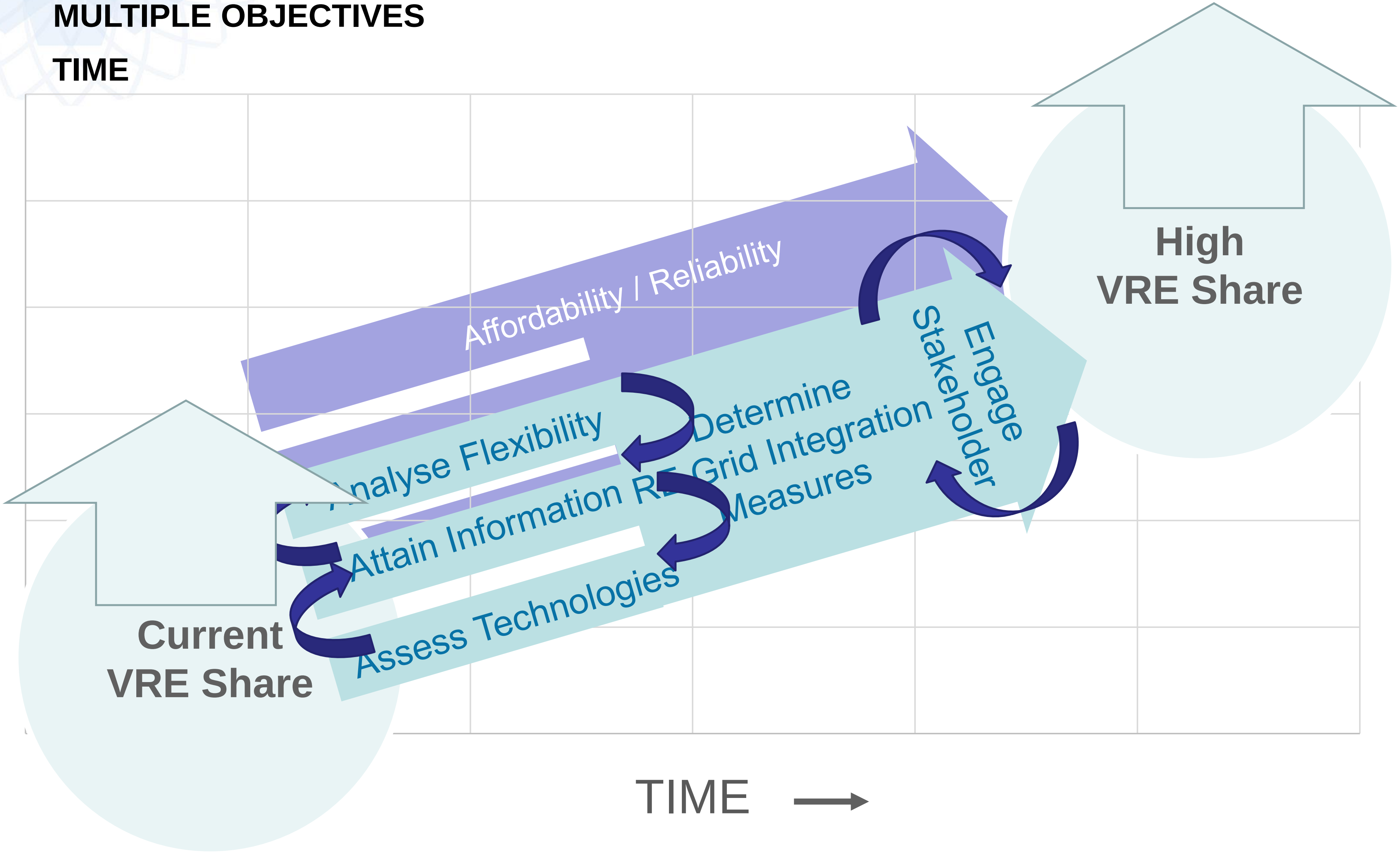
- Communication standards and protocols

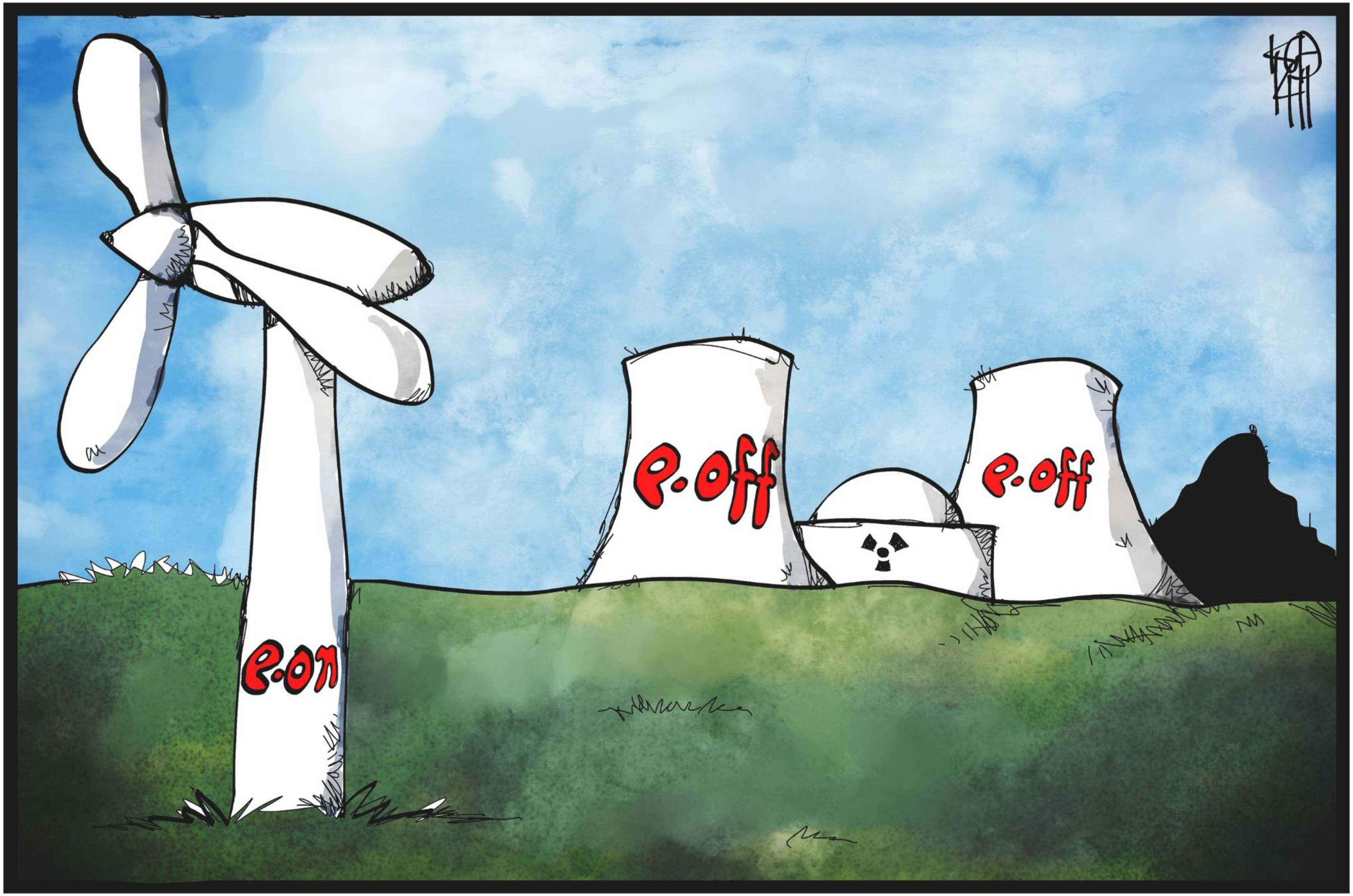
The scientific challenge

INTERDEPENDENCE

MULTIPLE OBJECTIVES

TIME

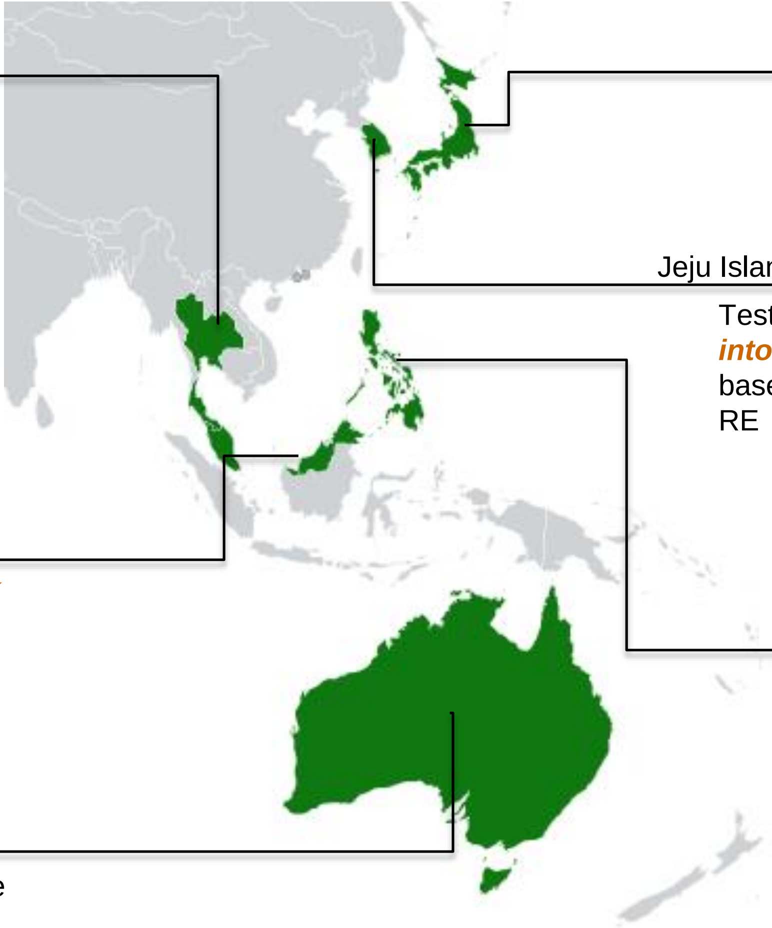



e-on
e-off
e-off

Case Studies

Country	Measure
Denmark	Grid Codes
Australia	Forecasting
Spain	Performing reporting
Germany	Market base RE dispatch
Turkey	Grid connection and access
New Zealand	Congestion management
Vanuatu	New tariff structures
USA	Data ownership rights
South Korea	Demand Side Management
GCC	Market integration and cooperation
Colombia	Capacity markets
Japan	Communication standards

Experiences in South East Asia



Thailand

The Alternative Energy Development Plan aims to increase consumption of RE by the ***deployment of DG (<10MW). Automatic Meter Reading (AMR)*** already in place.

Malaysia

New ***Regulatory framework*** with responsibilities for utility and RE developer

Australia

CSIRO convened the Future Grid Forum to assess the future high integration of RE and rise of the ***prosumers***.

Hachinoe, Japan

Project to reduce the impact of VRE by ***controlling DG output***

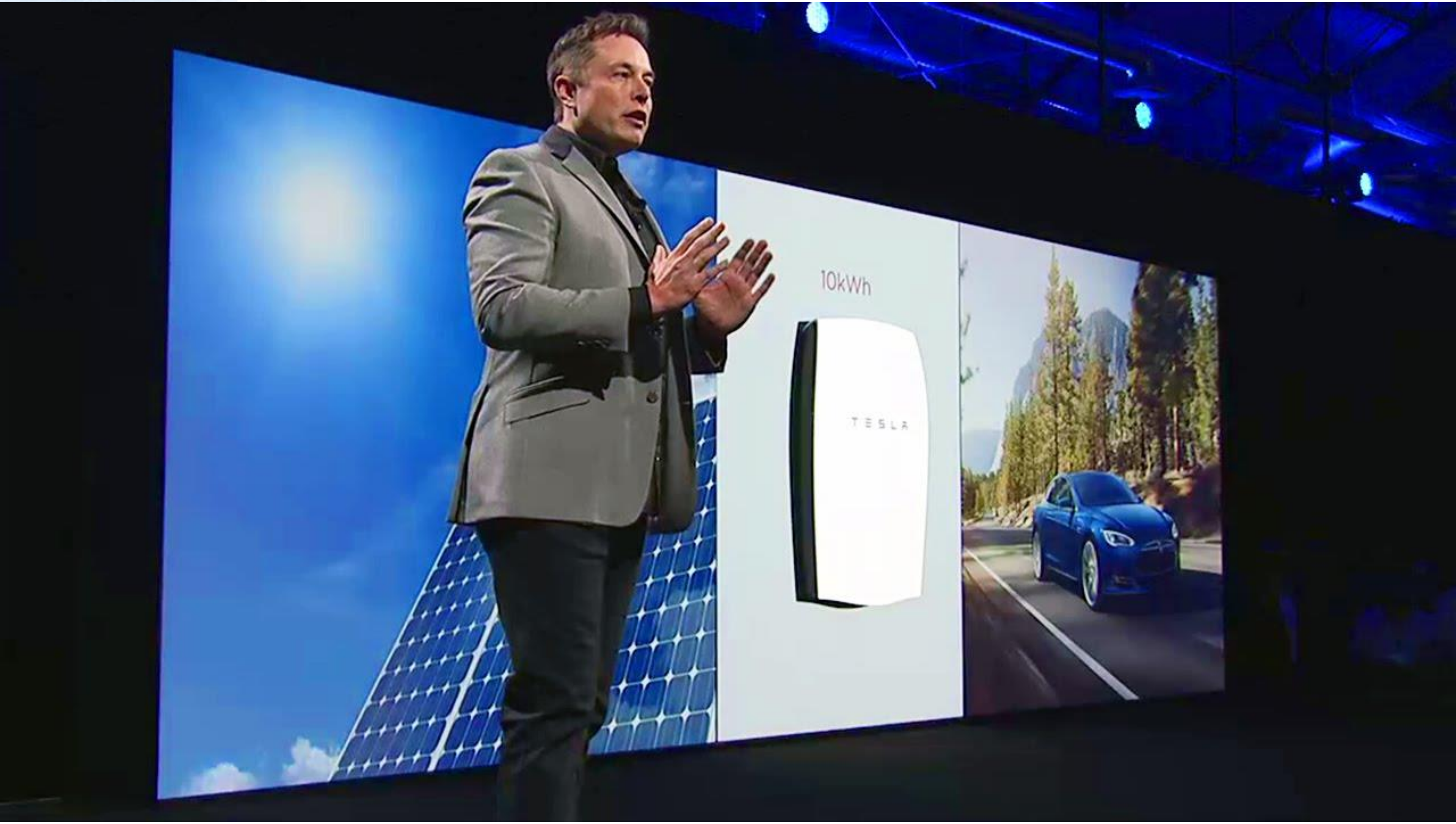
Jeju Island, South Korea

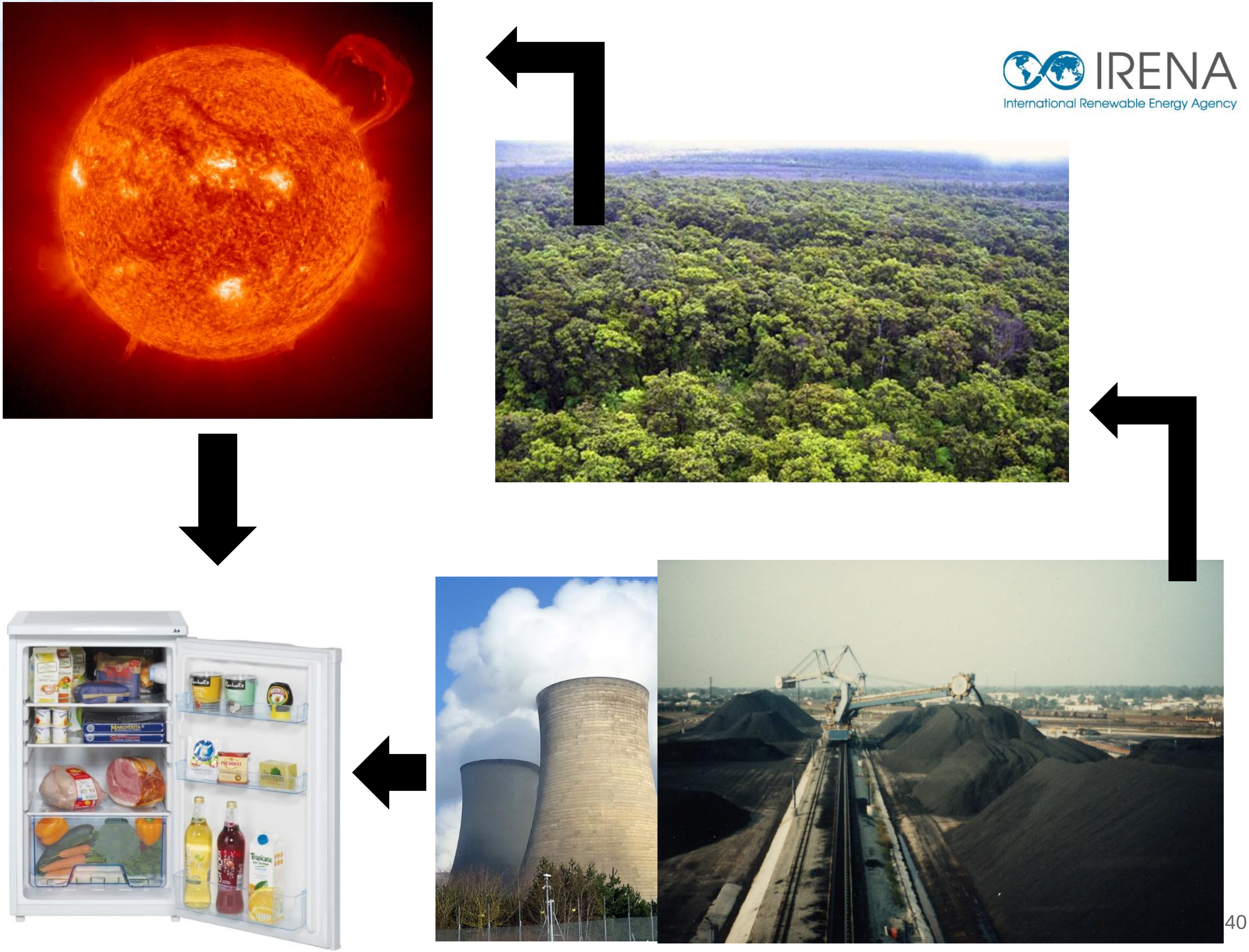
Test-bed project. ***Venture into new markets models*** based on smart grids and RE

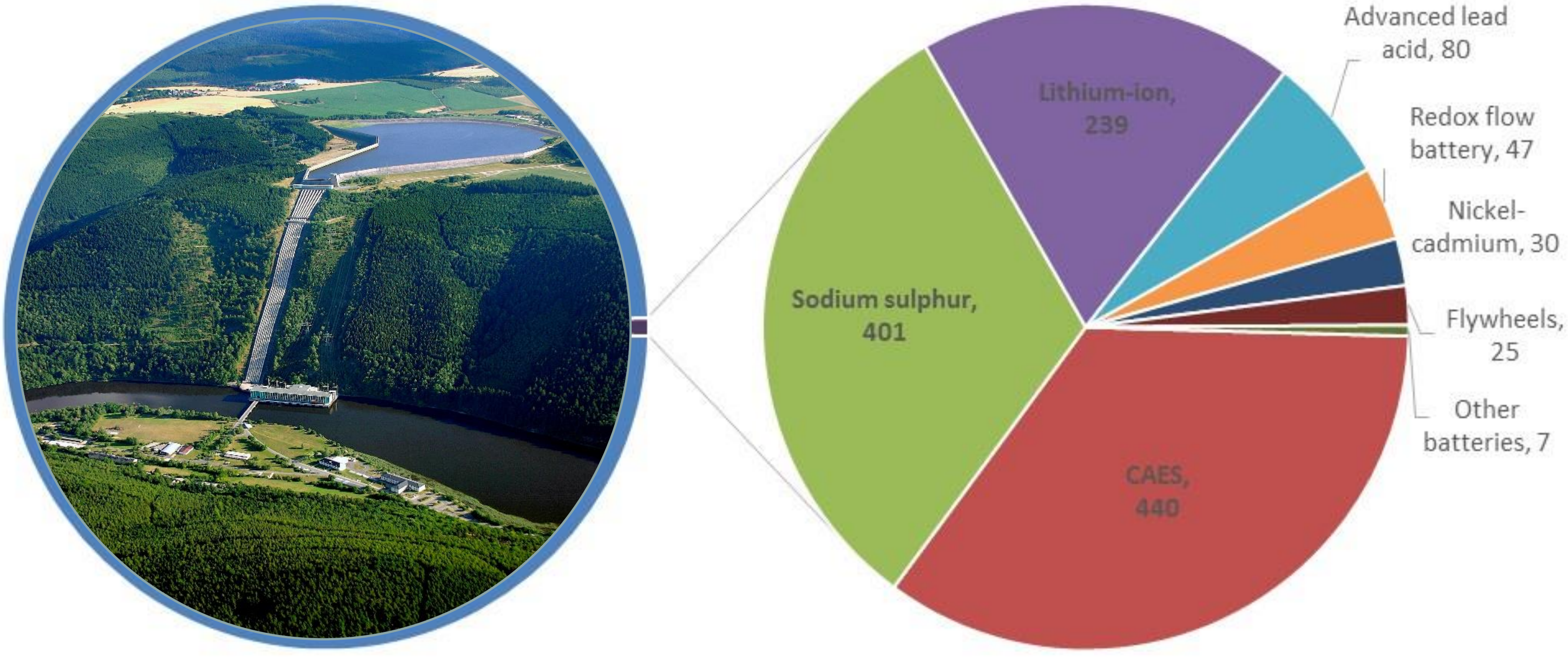
Philippines

Grid codes in place that cover specific aspects to the grid integration of VRE

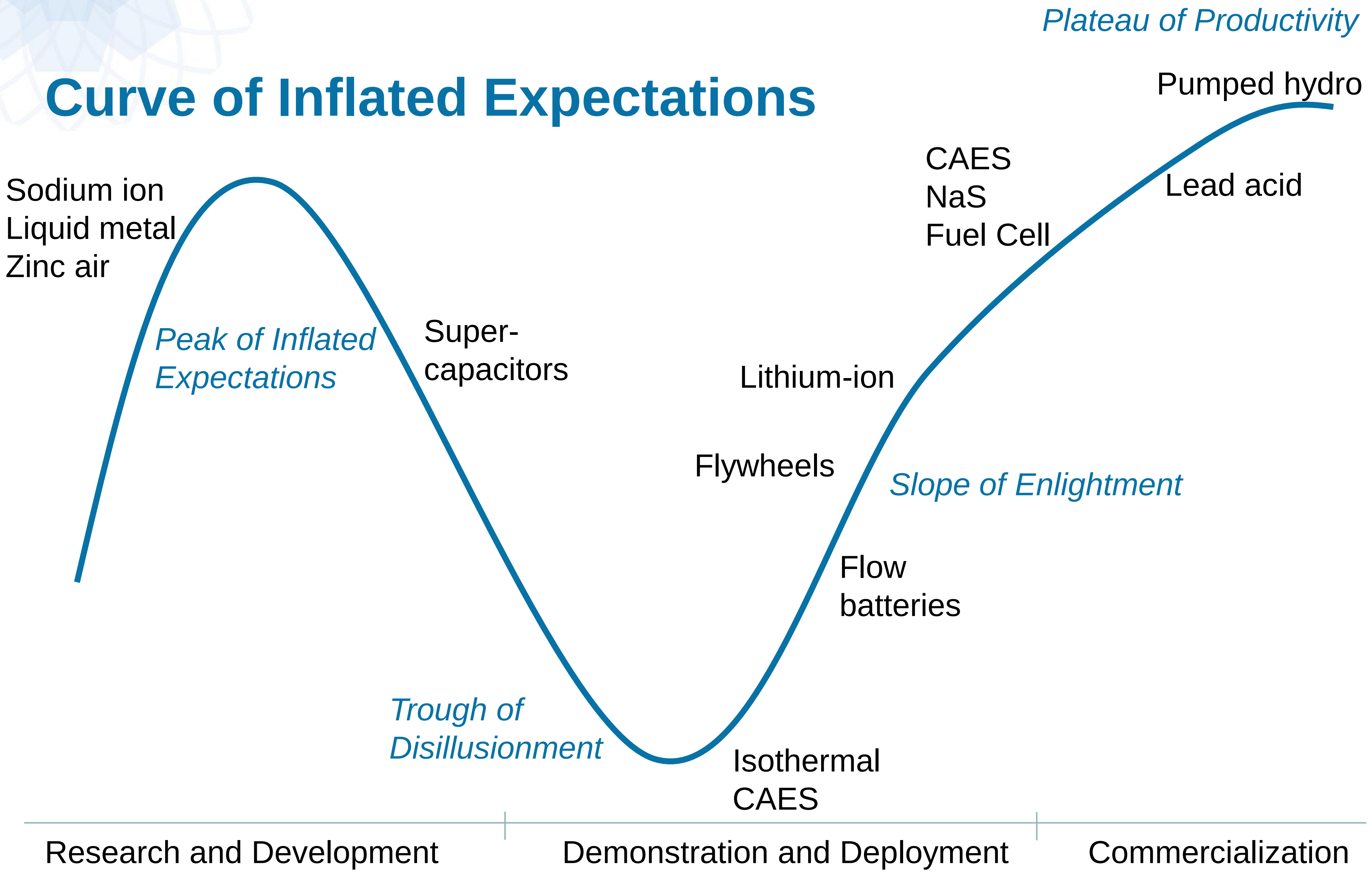
ELECTRICITY STORAGE


10kWh
TESLA




Advanced lead acid, 80
Redox flow battery, 47
Nickel-cadmium, 30
Flywheels, 25
Other batteries, 7
Lithium-ion, 239
Sodium sulphur, 401
CAES, 440

Curve of Inflated Expectations



Plateau of Productivity

Pumped hydro

Lead acid

CAES
NaS
Fuel Cell

Sodium ion
Liquid metal
Zinc air

Peak of Inflated Expectations

Super-capacitors

Lithium-ion

Flywheels

Slope of Enlightment

Flow batteries

Trough of Disillusionment

Isothermal CAES

Research and Development

Demonstration and Deployment

Commercialization

Diversity within technologies

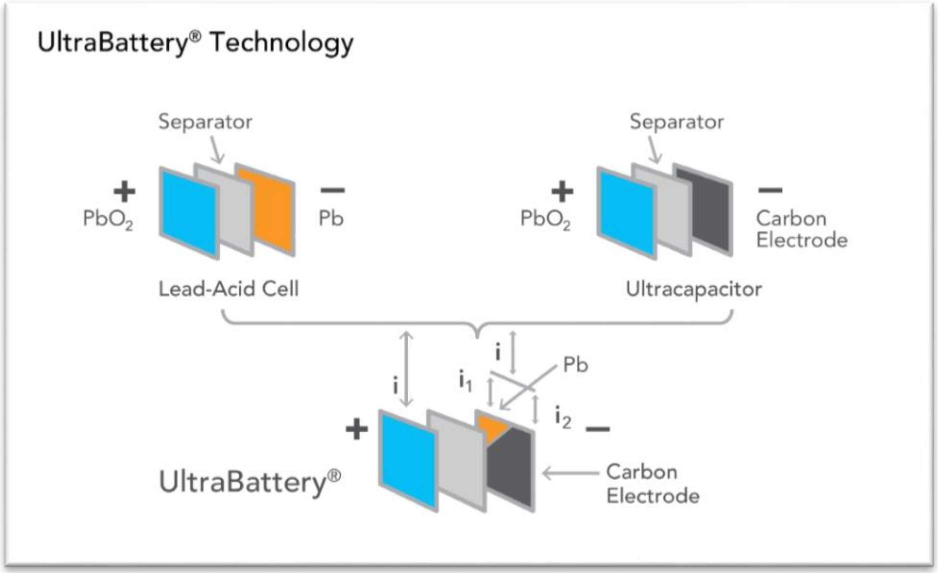
	Cathode	Anode	Electrolyte	Energy density	Cycle life	2014 price per kWh	Prominent manufacturers
Lithium iron phosphate	LFP	Graphite	Lithium carbonate	85-105 Wh/kg	200-2000	USD550-USD850	A123 Systems, BYD, Amperex, Lishen
Lithium manganese spinel	LMO	Graphite	Lithium carbonate	140-180 Wh/kg	800-2000	USD450-USD700	LG Chem, AESC, Samsung SDI
Lithium titanate	LMO	LTO	Lithium carbonate	80-95 Wh/kg	2000-25000	USD900-USD2,200	ATL, Toshiba, Leclanché, Microvast
Lithium cobalt oxide	LCO	Graphite	Lithium polymer	140-200 Wh/kg	300-800	USD250-USD500	Samsung SDI, BYD, LG Chem, Panasonic, ATL, Lishen
Lithium nickel cobalt aluminum	NCA	Graphite	Lithium carbonate	120-160 Wh/kg	800-5000	USD240-USD380	Panasonic, Samsung SDI
Lithium nickel manganese cobalt	NMC	Graphite, silicon	Lithium carbonate	120-140 Wh/kg	800-2000	USD550-USD750	Johnson Controls, Saft

Data from Navigant Research

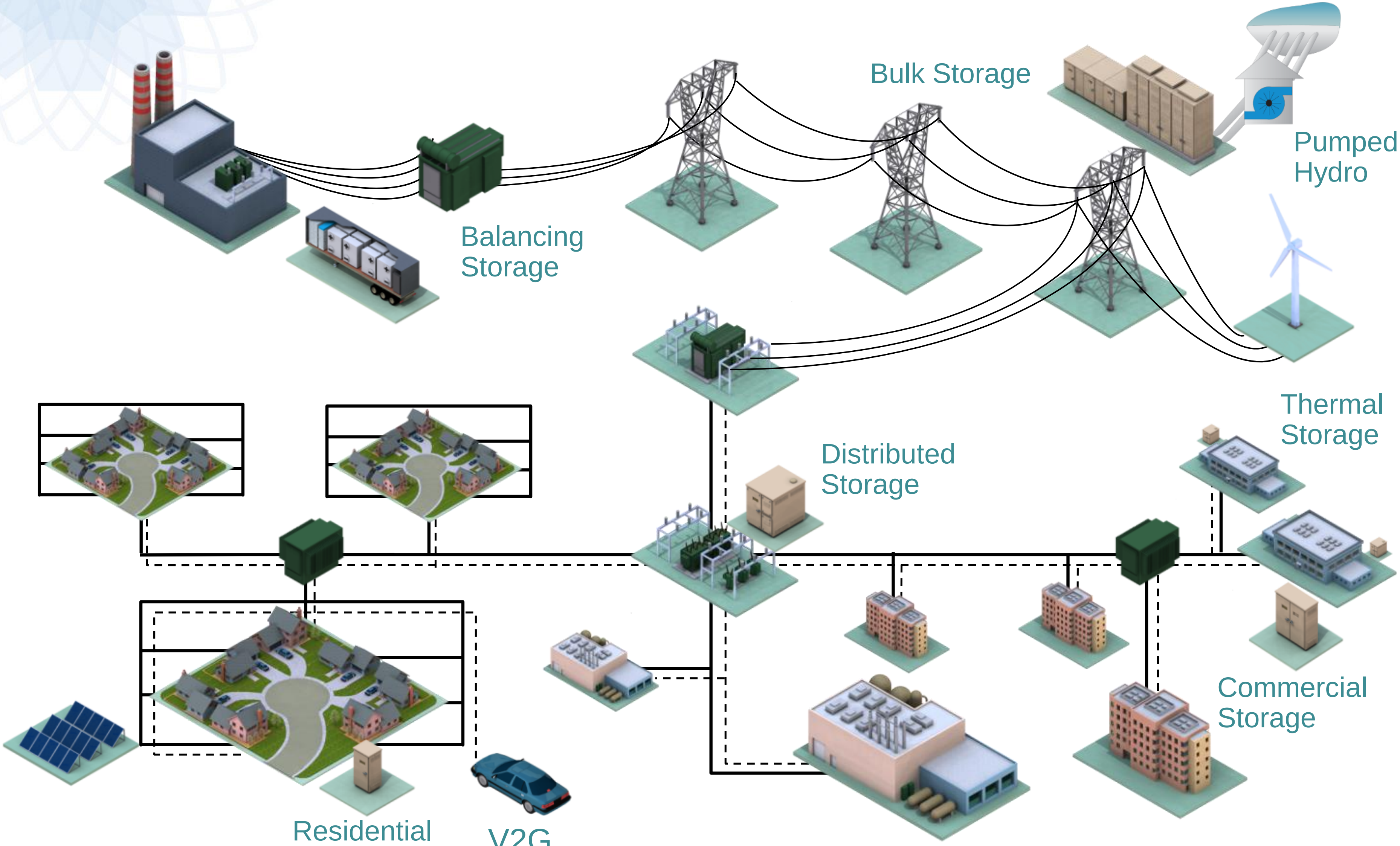
Hybrid options

Braderup: 2 MWh li-ion battery +
1 Mwh vanadium redox flow battery

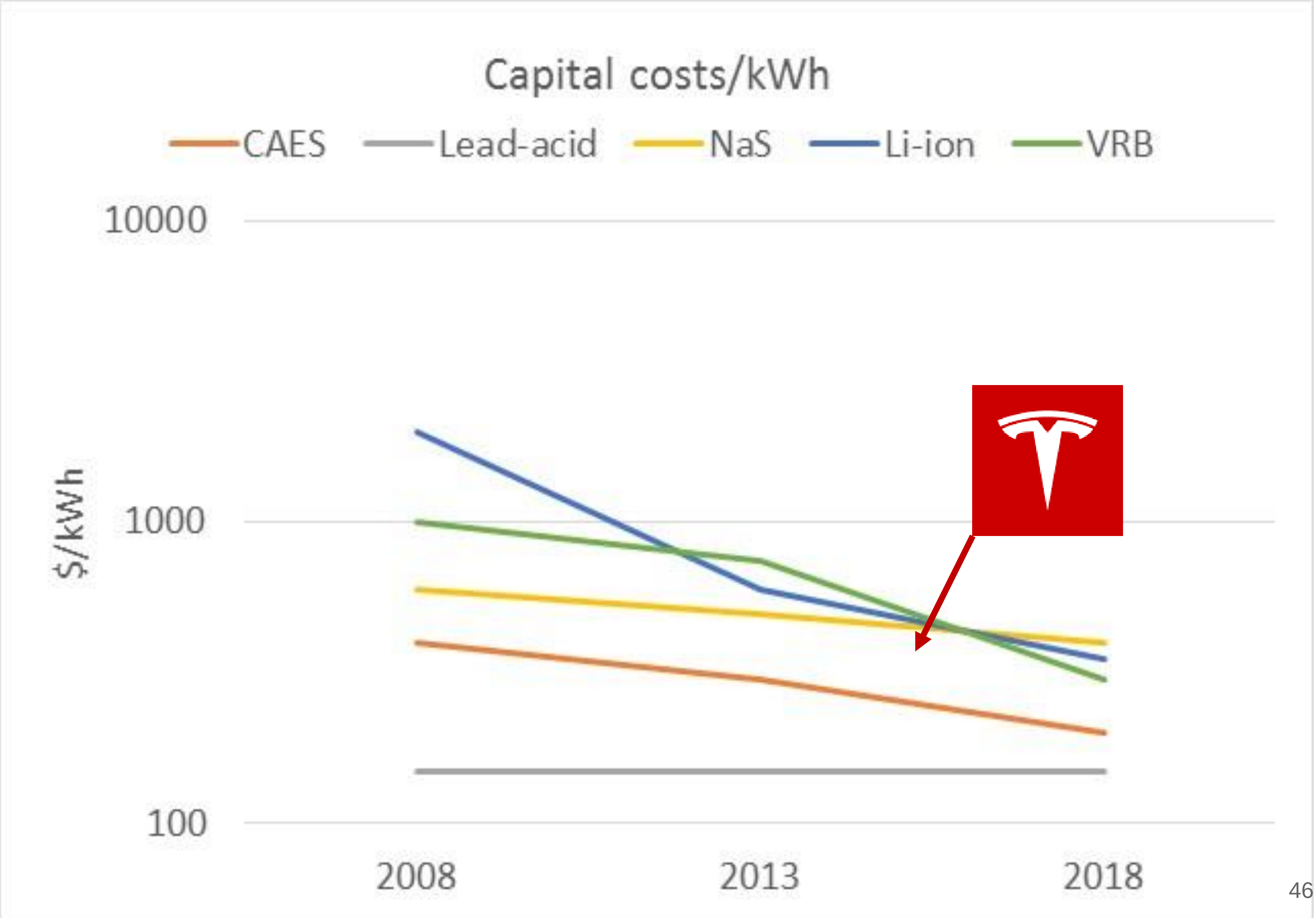
Aachen: 5 MW hybrid facility
with li-ion and lead-acid



Many potential energy storage locations and uses

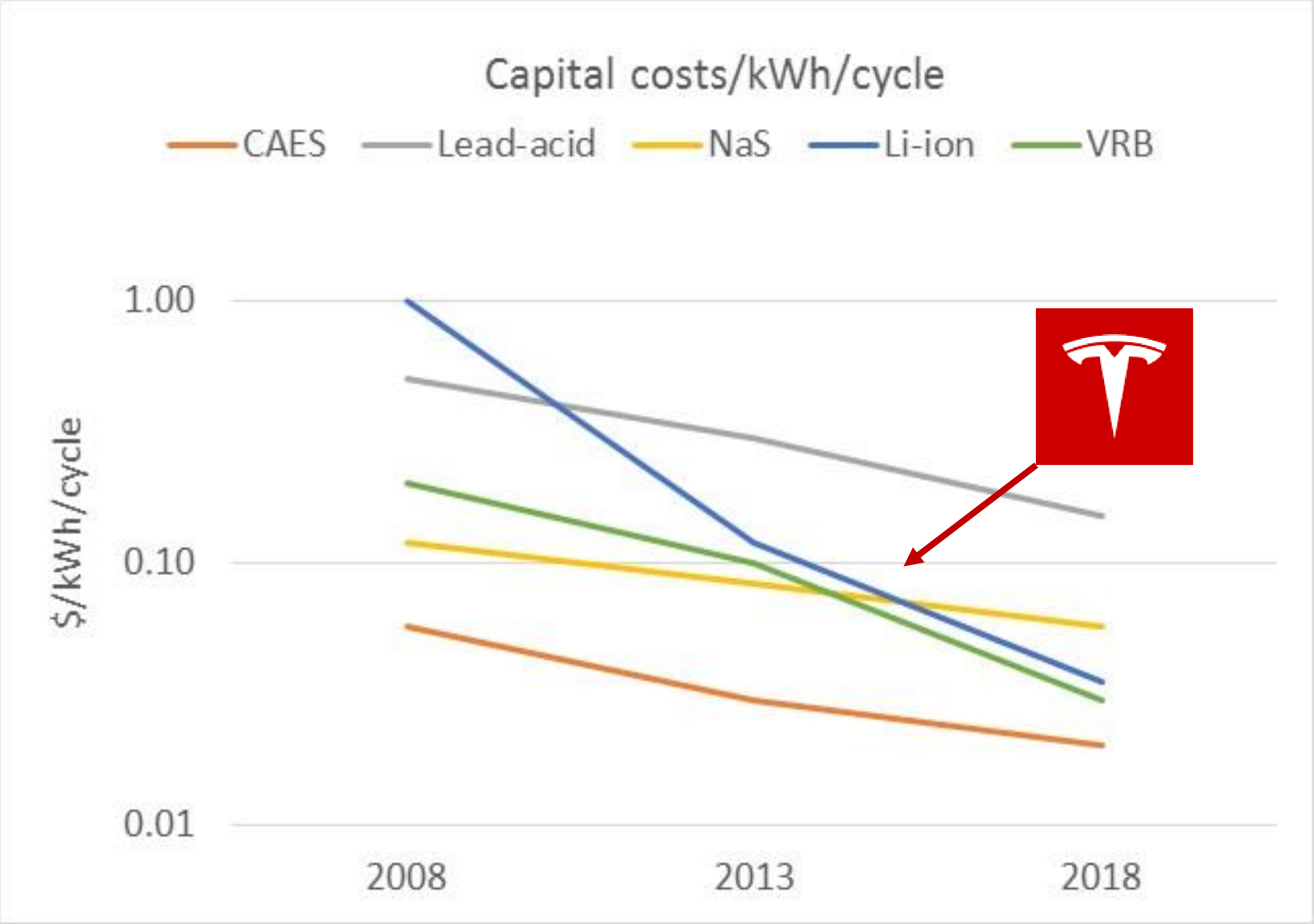


Electricity storage costs trends



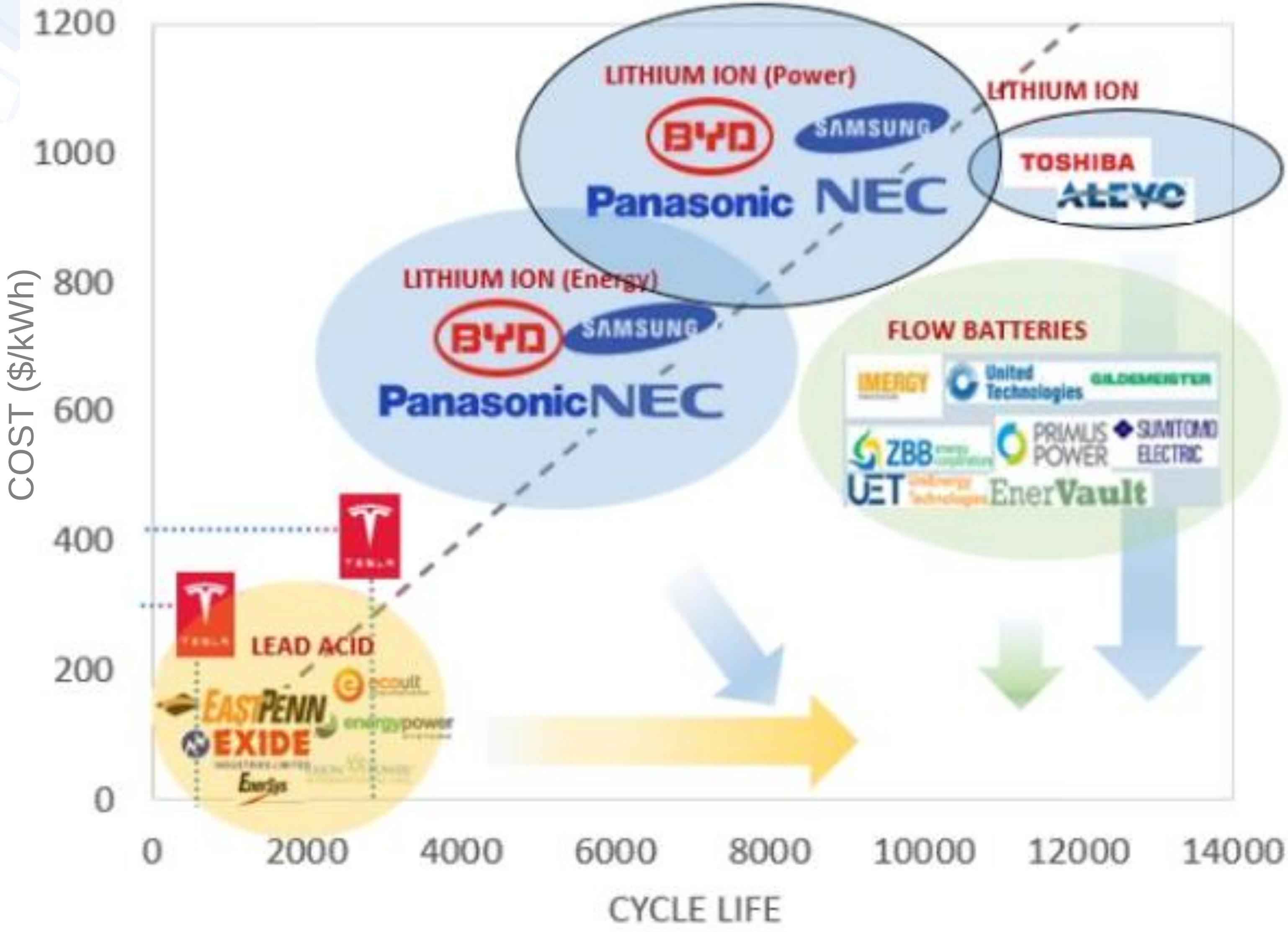
Source: IESA (2014) / Brattle (2012)

Electricity storage costs trends



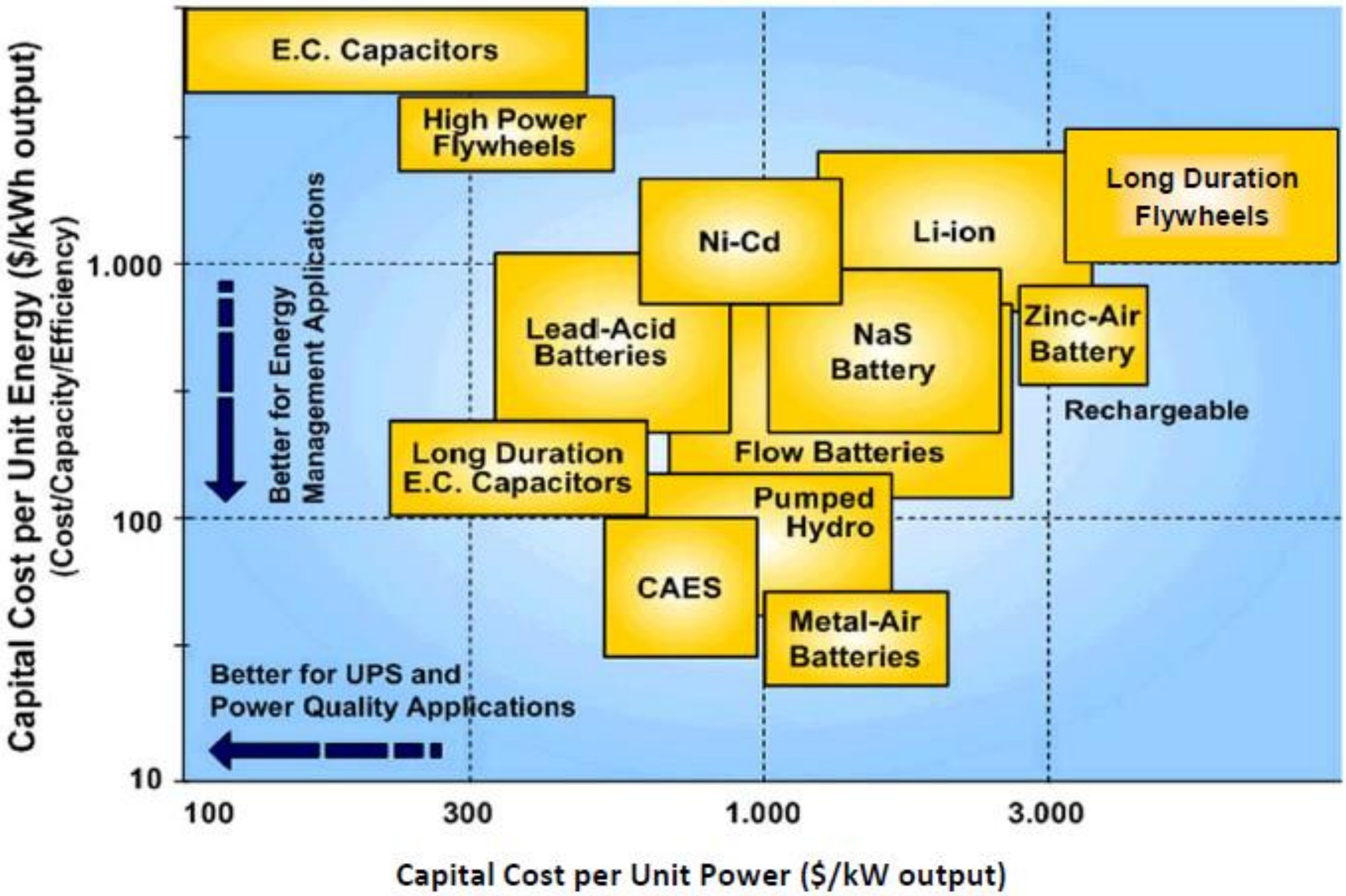
battery technology	lead-acid	li-ion	li-ion
battery power (kW)	5	5	5
battery capacity (kWh)	14.4	5.5	8
Depth of Discharge	50%	80%	100%
usable capacity (kWh)	7.2	4.4	8
cycles	2800	3000	6000
price (EUR)	8900	7500	18900
EUR/kW	1780	1500	3780
EUR/kWh	618	1364	2363
EUR/useable kWh	1236	1705	2363
EUR/useable kWh/cycle	0.44	0.57	0.39

In 2014, Li-ion electricity storage costs reduced to 1000 EUR/kW



Source: Customised Energy Solutions / IESA (2015)

Comparing storage options



Interactive and Iterative Process

Kick-off workshop

- Stakeholders feedback
- Send-out proceedings

Tokyo Workshop

- Stakeholders feedback
- Send-out proceedings

New Delhi Workshop

- Stakeholders feedback
- Send-out proceedings

Send-out **blueprint**

Dusseldorf concluding workshop

- Stakeholders feedback (also external)
- Send-out proceedings

Electricity Storage Roadmap

Roadmap Structure:
Opportunity areas and actions

SYSTEM ANALYSIS FOR STORAGE

- Engage and guide policy makers
- Provide value assessments
- Support system analysis of electricity/heat/fuel/ productive uses as storage options

STORAGE IN ISLANDS AND REMOTE AREAS

- Facilitate financing
- Create local value chains
- Develop a global database with practical example
- Guide policy makers to the required tools

CONSUMER-LOCATED STORAGE

- Comparative information sheets and labelling
- Accelerate standards on safety and recycling
- (Data) ownership and liability regulation

GENERATOR-LOCATED STORAGE

- Support the development of innovative regulation
- Support for localised/distributed systems

GRID-LOCATED STORAGE

- Pumped hydro and CAES analysis
- Demonstration projects for new business models

Storage located at the consumer side

Stakeholders vs. Actions

Stakeholders / Actions	Information sheets & labeling	Standards	Ownership regulation & Liability
Regulator	2.5	3.0	3.8
Storage/RE generation developers	3.8	3.3	2.0
Industry associations	3.5	3.3	1.0
Consumer associations	3.3	2.0	3.3
Insurance companies	2.3	2.3	2.8
Standard bodies	3.0	3.8	1.8
Distribution system operators	1.5	2.5	3.3

Conclusions

- Storage can be transformative, but it is in the middle of a development process needs clear guidance.
- It is crucial to engage and guide stakeholders along the entire development process
- In the short-term, islands and remote areas are potential opportunity areas for the development and deployment of electricity storage systems (ESS). Financing is crucial.
- In the medium and long-term, the development of ESS should be guided by an analysis and planning models of the system as a whole. Evaluate other available technologies (Pumped Hydro Storage)
- There should be a clear definition and valuation of flexibility, which must be reflected in the regulatory framework
- In order to establish an efficient regulatory framework, it is needed to analyse and determine what are the real needs and what is the regulation aiming to.

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Renewable Energy Grid Integration Activities

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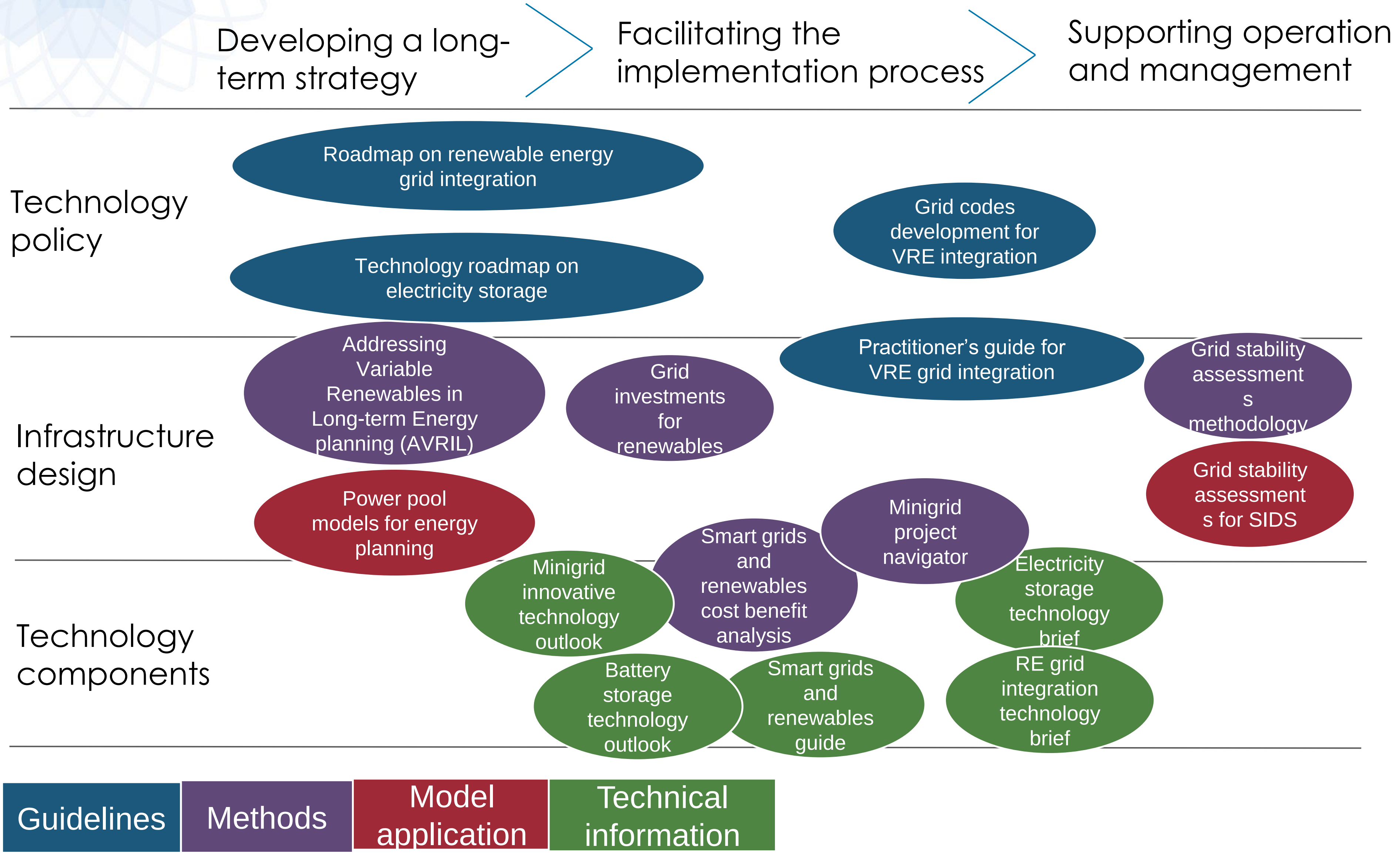

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